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SAMPLING AND DATA GATHERING STRATEGIES FOR FUTURE USAF ANTHROPOMETRY

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AEROSPACE MEDICAL DIVISION
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Beginning with a comprehensive review of anthropometric resources already available, this report serves as a guide to more refined and less costly methods of acquiring needed anthropometric data to meet changing military requirements and to accommodate changing military populations. Many sampling schemes are described and evaluated for their utility in meeting specific USAF needs. Various measurement and sampling errors

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are discussed and the effects of each type of error on the statistics of major importance in design problems are explained.

The authors offer a definition of adequate accuracy based on a detailed statistical analysis and demonstrate that such accuracy can be obtained from random samples of 350 and matched samples of much fewer subjects. They suggest that with the completion of currently on-going anthropometric surveys no further data-gathering of U.S. military personnel on a massive scale need be undertaken.

A multi-faceted plan for the future acquisition of USAF anthropometric data is recommended. The plan incorporates specific steps designed to up-date basic population data, follow and project secular trends and devise surveys tailored to obtain specific task-oriented information.

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PREFACE

This study was conducted under Project 7184, "Human Engineering in Advanced Systems," Task 718408, "Anthropology for Design," Work Unit 71840821, "Air Force Body Size Variability," with support provided from the Laboratory Director's Funds.

Project scientists were Mr. Edmund Churchill and Dr. John T. McConville, Anthropology Research Project, Webb Associates, under contract AF33615-73-C-4066, with Mr. C. E. Clauser acting as contract monitor for the Aerospace Medical Research Laboratory.

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Ms. Ilse Tebbetts and Ms. Jane Reese, Webb Associates, edited and prepared the manuscript for publication.

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CHAPTER I

INTRODUCTION

"Anthropometry...is a growing discipline in which new and more sophisticated approaches are sought to handle old problems" (Zeigen et al., 1960).

It is now a quarter of a century since the USAF's first major anthropometric data-gathering operation was launched. This 1950 survey of USAF flying personnel was in many ways a precedent-establishing enterprise. It measured men far more thoroughly than men in groups of thousands had ever been measured before. Its subjects were members of the USAF on active duty rather than, as in most earlier military surveys, men at the point of leaving or entering the service.

The survey report itself broke new ground. In its selection of statistics and method of presenting them and in its documentation of the measuring techniques and survey procedures, it has served as a model for reports of most major military anthropometric surveys conducted throughout the world since that time. For almost two decades the 1950 document was the major source of body size data employed in the design of clothing and equipment used by American adult males--civilian as well as military. Of equal importance is the fact that material in the report served as the basis for studying the statistical nature of body size data.

Today, almost twenty major military anthropometric surveys later, substantial resources are available to assist USAF

anthropometrists in the planning and execution of their work. The sheer bulk of the available USAF and other body size data, the wealth of experience gained during the past twenty or so years in using these data and the broad knowledge of their statistical properties, as well as the means for rapid computational analysis and numerical approximations, have immeasurably expanded the array of tools which can be brought to bear in solving problems of designing and fitting. The military population has undergone changes with time as have individuals within that population; clothing which must be designed to fit and equipment which must be devised to accommodate its users have altered considerably but the essential problem--that of dealing with the considerable variability of the human subject--remains. It seems highly appropriate, therefore, to consider how best to use the substantial resources at our command in the search for "more sophisticated approaches... to...old problems."

The initial step in the application of anthropometric data to problems of design and fit is, of course, the acquisition of the material. It is reasonable, therefore, that a search for new approaches begin with a consideration of methods of data acquisition. This report is primarily concerned with that subject. We will review the resources currently available, discuss the types of data which the USAF needs, and outline a variety of sampling strategies. We will discuss in some detail various kinds of measurement and sampling errors and the effects of each type of error on the statistics of major importance in

design problems. We will offer an objective definition of "adequate accuracy", and demonstrate that this accuracy can be obtained from random samples of 350 and matched samples of substantially fewer subjects.

The report will conclude with recommendations for a multi-faceted plan for the ongoing acquisition of USAF body size data. The approach we suggest would be less costly and more responsive to the needs of the USAF than periodic massive surveys similar to the 1950 and 1967 surveys of flying personnel.

CHAPTER II

MILITARY ANTHROPOMETRIC SURVEYS: A HISTORICAL REVIEW

The anthropometric surveys of U. S. military forces have a long and honorable history in documenting the body size variability of the American population. The earliest such studies were those conducted at the close of the Civil War and reported by Gould (1869) and Baxter (1875). The former study was limited to the measurement of stature, weight, and chest circumference but was the first systematic large-scale sampling of the body sizes of U. S. military males. Baxter's study of Union soldiers at demobilization, was conducted on a smaller scale but included a number of other body measurements of interest to anthropologists and clothiers. It was not until the close of World War I, when the Adjutant General issued instructions that 100,000 men be measured at demobilization, that additional anthropometry of U. S. military men was obtained. In this study all the linear and circumferential dimensions considered to be of interest to anthropologists were measured.

The Civil War studies were medically oriented. Emphasis in the World War I study was on data related to the sizing of uniforms but it is apparent that the information gathered, while of considerable anthropological value, was little used for sizing purposes. The chief application of all the data obtained until World War II was in the establishment of recruitment standards for body size, health and stamina.

In the summer of 1940, Colonel Otis O. Benson, Jr. of the Aero Medical Research Unit at Wright Field, Ohio, became aware of the increasing importance of body sizing problems in aviation. Prior to this time the small Army Air Force had maintained relatively stringent body size limits for flight personnel. Fighter pilots, for example, could not exceed a maximum stature of 70 inches or a maximum weight of 180 pounds. With the need for rapid expansion of the Army Air Force on the entry of the United States into World War II, it became necessary to broaden the body size limits to obtain the large number of flying personnel needed. Even so, the Army Air Force flying personnel continued to be a very select group and its expansion alone would not have spurred the AAF to seek anthropometric data of the kind available to the Ground and Service Forces from earlier World War I studies. It remained for a plaguing problem related to the design of gun turrets to provide the impetus.

The design of the turrets had initially been dictated by the air frame configuration and the performance requirements established for the aircraft. The resulting turret imposed severe limitations on the physical size of its human occupants and consequently on the number of gunners able to operate it. Acting on the recommendations of Dr. E. A. Hooten, who had been called in as a consultant, Colonel Benson organized an anthropology group at Wright Field whose first task was to conduct a general anthropometric survey to determine: the body size of the then current cadets and gunners; what proportion of the men

could use existing equipment; what size criteria should be used in the future selection of air crew members, and how existing equipment might be modified and future equipment designed to accommodate the largest possible number of air crew men.

The entry of the U.S. into World War II occurred during the planning of the survey but, despite the pressure of conflicting priorities, the Air Surgeon directed that the survey proceed. The body of data gathered during this period provided the engineering anthropometry for the design of the majority of World War II aircraft and equipment (Randall, et al., 1946). This survey was followed by a number of limited studies, such as the facial survey of 1943, which were needed to supplement the original survey data for specific items of equipment. It is interesting to note that a modified A-13 oxygen mask, the facepiece for which was based on the 1943 facial data, is still being manufactured and sold both in the United States and abroad.

The work of the anthropologists at Wright Field provided a model for similar groups that were formed to work with the other services. The Armored Forces Anthropometric Survey, a Navy Aviation Survey, and the Army Quartermaster's Survey of 100,000 male ground forces and 8,000 nurses and other women at demobilization broadened the knowledge of the body size of the U. S. military population.

Following World War II, the advent of new aircraft, new missions and, above all, new classes of personal protective equipment such as partial and full pressure suits required that additional anthropometric data be obtained on the U. S. Air

Force population. To that end a survey of the flying population was conducted in 1950 (Hertzberg, et al., 1954). By way of contrast to the three body dimensions measured on Union troops at the end of the Civil War and the thirty-three measured on Army aviation personnel in 1942, 132 dimensions were measured on the subjects in the 1950 survey. Since the 1950 USAF Survey, each of the military services has conducted one or more anthropometric surveys so that we now have a wealth of body size data on the military population of the United States.

A massive quantity of complete survey data is currently stored in the Anthropometric Data Bank at the Aerospace Medical Research Laboratory (AMRL). Table I lists the available material including survey population, date, number of variables measured, and number of subjects. Supplementing the information in the data bank are a number of detailed studies on such subjects as the anthropometry of the head and working positions* which are also available at AMRL for further analysis and study as the need arises.

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* For a comprehensive listing of these studies, see the citations in Reid, Betty, 1973, An Annotated Bibliography of USAF Applied Physical Anthropometry, January 1946 - May 1973, AMRL-TR-73-51.

TABLE I

CURRENT HOLDINGS IN AMRL ANTHROPOMETRIC DATA BANK

Survey	Number of Anthropometric Variables*	Approximate Sample Size
1946 U.S. Army Survey, Male	66	25000
Female	66	8000
1950 USAF Flying Population	133	4000
1952 USAF Female Basic Trainees	63	850
1952 USAF Male Basic Trainees	60	3000
1957 USAF PhotoMetriC	107	2200
1959 U.S. Army Pilots	43	500
1960 NATO Turkish Military	149	1000
1960-1 NATO Greek Military	149	1100
1961 NATO Italian Military	149	1400
1961 Korean Air Force Survey	133	250
1962 Japanese Air Force Survey	62	250
1964 Vietnam Ground Forces	51	2200
1964 U.S. Navy Flying Personnel	98	1500
1965 USAF Survey	161	4000
1965-6 U.S. Army Ground Forces	73	6500
1965-6 U.S. Navy Enlisted Men	73	4000
1965-6 U.S. Marine Enlisted Men	73	2000
1967 USAF Survey (Flying Personnel)	190	2500
1968 USAF Women	140	2000
1967-8 German Air Force Survey	154	1500
1968-9 Iranian Military	71	9000
1970 U.S. Army Aviators	88	1500
1970-1 RAF Aircrew	72	2000
1972 RAF Aircrew Heads	45	500
1974 NEL Law Enforcement Officers	23	3000

* Including, for some surveys, age, muscle strength and reported stature and weight as well as body size measures.

While the number of dimensions measured in a given survey has increased markedly from the 33 measurements taken in the 1942 Army Air Force Survey to 187 in the most recent 1967 USAF Survey of flying personnel, the available data are not yet complete and do not provide information on body dimensions for every conceivable design problem of the future. Nevertheless, the AMRL Anthropometric Data Bank is unique. Its comprehensive compilation of anthropometric data can provide users with an excellent understanding of the interrelationships among the measured variables as well as a powerful knowledge of past and present trends in the body size of military populations.

CHAPTER III

BODY SIZE DIMENSIONS AND DYNAMICS

One has only to view a group of people to be struck by the range of diversity in the size and shape of mankind. This diversity, often visually aesthetic, can be a source of annoyance to the designer. For those involved in design problems, the human body has an inordinate number of irregularly curved surfaces and angular projections, as well as an assortment of appendages, all of which tend to impede a straightforward design solution. Altogether, man lacks the proper degree of reproductive quality control to make a satisfactory design subject.

Despite the quality of the subject material, the designer of military equipment and systems must arrive at a design solution which will be adequate to accommodate the irregularities of size and shape of potential users. It is of value, therefore, to have as detailed a quantification of body size variability of the design population as possible.

Man, individually and collectively, is a manifestation of his genetic heritage, modified by external factors such as nutrition, disease, and trauma. One can, in a general fashion, classify the total human morphological variability into the three broad categories of intra-individual, inter-individual, and secular variability. Intra-individual variability pertains to those changes which take place in an individual through time, primarily as a function of growth, maturity and senescence.

Such variability is generally of minor significance in an adult of military age since the major changes occur during childhood, adolescence and old age. This is not to say that an individual is in an absolute state of morphological stability between the ages of 18 and 55. Among American adults there is often an increase in body weight with accompanying increases in associated body girths during maturity. In general, however, these changes are not significant and their effects can safely be ignored for our purposes.

Of principal concern to USAF are inter-individual differences.

The differences between the sexes are a major source of such variability with the female having, in general, a smaller overall body size with far less pronounced or rugged features than the male. A second source of such variability lies in ethnic and racial origins. While all living people belong to a single biological species, the species, like other life forms, is not geographically uniform; it is differentiated into a number of local variants or breeding groups. These variants frequently differ in a number of morphological traits such as skin, eye and hair color, body size and proportions, with a particular trait often highly characteristic for a single strain. It is not necessary here to probe for the reasons behind these morphological differences between variants of man but only to acknowledge their existence and attempt to deal with them in terms of sizing and design requirements. This variability is of some importance here because of the many ethnic and racial groups that constitute the American military population.

In biological populations many morphological traits, particularly of size and shape, are continuous rather than discrete and are distributed "normally". For many traits the frequency of measured values approximates the "normal" bell shaped distribution curve illustrated in Figure 1, below.

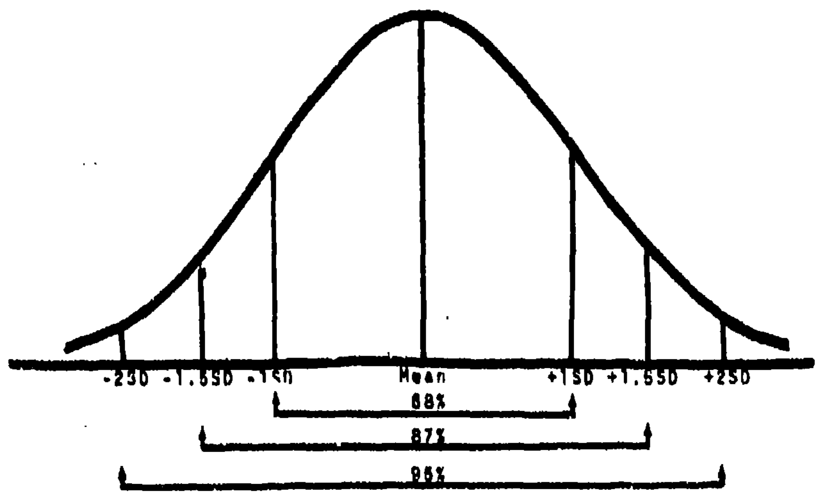

Figure 1. The Normal Curve.

The width of the curve approximates the range of variability for a particular dimension from smallest to largest and the height of the curve the anticipated frequency for any particular measured value. For a particular trait, these values tend to cluster around the center or mean value and are less frequent toward the ends of the curve. The standard deviation (SD), describes the variation in the distribution around the mean value with about two-thirds of the measured values lying within ± 1SD of the mean, about 95% within ± 2SD's of the mean, etc. The two tails of the distribution represent those individuals who are

most dissimilar from the majority of the population for that particular trait. These individuals may be clinically normal but exceptional in size and shape; for example, Wilt Chamberlain, a professional basketball player, Dave Foley, a professional football player, and Eddy Arcaro, a professional jockey, are extremely divergent in size and shape but could all conceivably be found in a military population. The normal range of variability in terms of size and shape is, therefore, quite broad even without such factors as sex, race and ethnic origin.

There are, in addition, individuals in the active working population of the U. S. who suffer from malnutrition or diseases such as pituitary dwarfism or acromegalia but, in all probability, such people would not be found in the military population.

A final source of human variability which is here termed secular concerns changes which occur from generation to generation. Though not well understood this factor is of some importance in systems design. The lengthy lead time required for the production of modern aircraft and weapons systems is such that the crew members who will eventually use them are often not even of military age when the design specifications are fixed. It is of more than casual interest, therefore, to determine what the physical size and proportions of the military population will be at a given point in the future.

There has been a generally perceptible increase in body size of the military over the past century. The magnitude of this change is demonstrated in Table II below which compares

the mean stature and weight of U. S. Army populations at different periods of time.

TABLE II

MEAN STATURE, WEIGHT AND AGE OF U. S. ARMY SOLDIERS*

	Stature	Weight	Age
Northern Civil War Recruits (1863)	67.5	136.0	---
Northern Civil War Veterans (1865)	67.7	139.0	---
World War I Veterans (1919)	67.5	141.5	---
World War II Veterans (1942)	68.4	154.8	22.2
U. S. Army (1966)	68.7	159.1	24.3

* Stature in inches, weight in pounds, age in years.

It is unlikely that such increases will continue indefinitely but even with a diminution in magnitude, secular changes in body size will probably continue to be sufficient to warrant consideration in design problems.

Thus, while it may be feasible to disregard intra-individual variation in the design of military equipment and systems, it is apparent that inter-individual and secular body size variability must be considered.

Inter-individual Variations

Since we have amassed a considerable body of knowledge on the subject of morphological variation, it is possible to quantify this variability to determine its significance in design studies. Differences in body size between the sexes can be assessed by using the U. S. Air Force male (1967) and female (1968) survey data. Selected body dimensions are compared in Table III.

TABLE III

COMPARISON OF MALE AND FEMALE BODY SIZE VALUES (USAF Data)*

	USAF Fliers			USAF Women			Ratio of Mean Values
	$\bar{X}$	(SD)	V	$\bar{X}$	(SD)	V	(F/M) x 100
Age	29.5	6.3		22.9	6.4		
Stature	177.3	6.2	3.5%	162.1	6.0	3.7%	91.4
Weight	78.7	9.7	12.3%	57.7	7.5	13.0%	73.3
Sitting Ht	93.2	3.2	3.4%	85.6	3.2	3.7%	91.8
Thumb-Tip Reach	80.3	4.0	5.0%	74.1	3.9	5.3%	92.2
Buttock/Knee Lgth	60.4	2.7	4.5%	57.4	2.6	4.5%	95.0
Vertical Trunk Circumference	168.1	7.2	4.3%	154.4	6.9	4.5%	91.8
Cube Root of Wt	4.3	0.2	4.1%	3.9	0.2	4.3%	90.7

* Age in years, weight in kg, all other measured values in cm.

The male fliers are older, larger, and heavier than the Air Force women, as might be expected. It has been an accepted rule of thumb that female measurements tend to average about 92% of comparable male values. The ratios shown in Table III indicate that for linear measurements (i.e., all but weight) the rule holds reasonably well for these samples. The coefficients of variation of the linear measurements are quite similar for the two samples. The mean and standard deviation of the women's weights are about three-quarters of those for the men, a pattern similar to that seen in the 1962 U. S. Health Survey for similar male and female age groups. To properly equate weight, an essentially three-dimensional quantity, with the linear measures, the cube roots of the weights are computed. When this is done, the female to male ratio becomes 90.2%, a value clearly consistent with the 92% rule of thumb.

If the male/female differences in the mean values for most body dimensions average only about 8%, then what is the significance of this difference for design purposes? A bivariate distribution of height and weight for the samples is shown in Figure 2. Each ellipse encompasses ~95% of its respective sample. While there is considerable overlap, it is readily apparent that the two groups are quite distinct in these two variables and, because of the well known relationship of many other body dimensions to height and weight, in other aspects of body size as well. Since the standard deviations of body size values, male or female, average about 5% of the mean, a difference of 8% would mean, in general, that the body size of females approximately one standard deviation <u>above</u> the female mean value would tend to match the body size of the males approximately one standard deviation <u>below</u> the male mean value. This means that system or equipment design based on the anthropometry of the male fliers, for example, must be modified if it is to accommodate the body size differences of female users--a matter of some importance as women are now assuming far broader roles than ever before in the military services.

Body size variability related to ethnic/racial groups is of considerable interest because of the broad spectrum of national origins which characterizes the American population. Some information on the ethnic and racial makeup of the U. S. population, as obtained from the 1970 Census, is shown in Table IV.

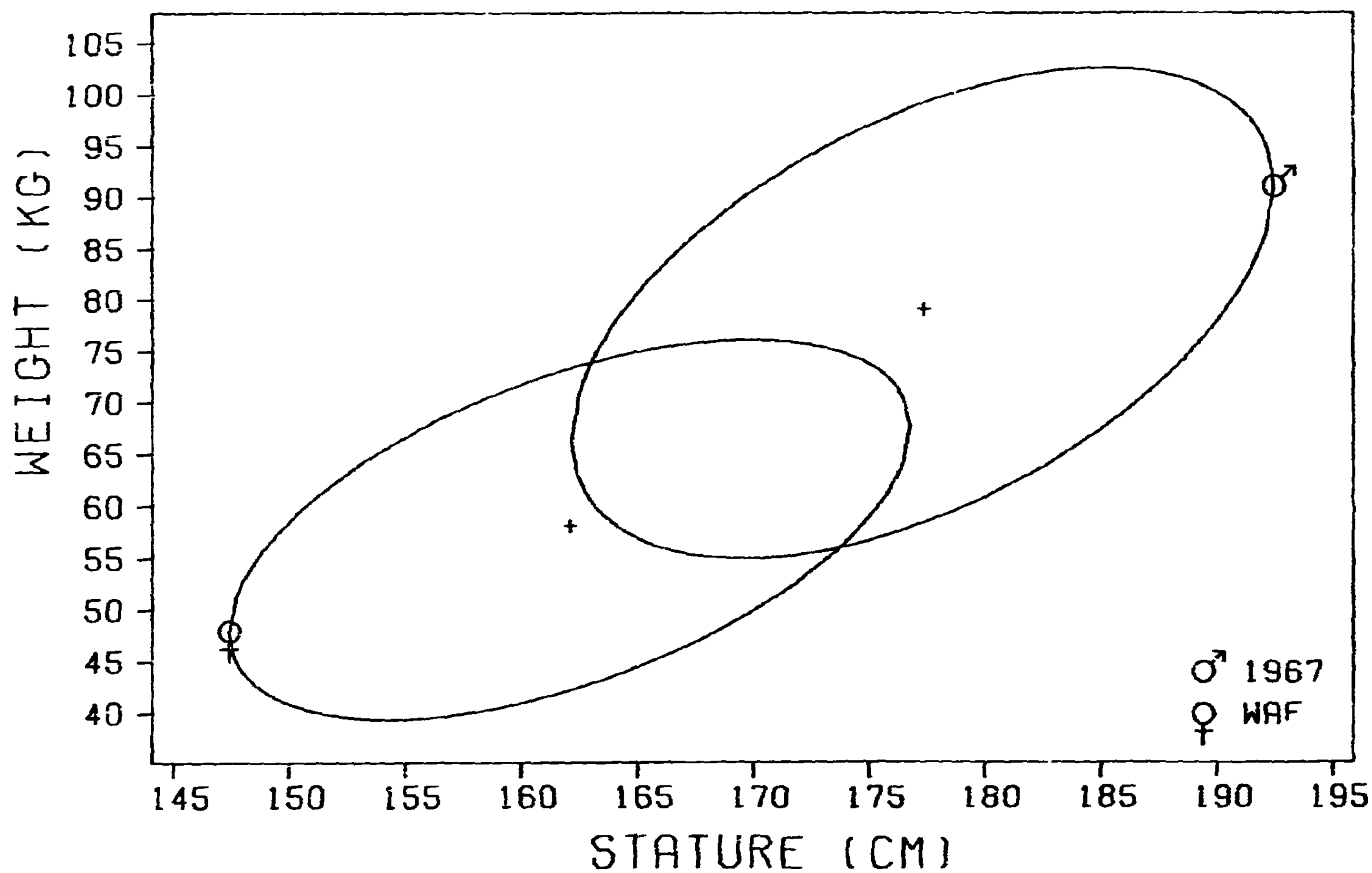

Figure 2.

Distributions of Stature and Weight for U. S. Air Force Personnel - Male and Female

(Approximately 95% of each group is contained within the appropriate ellipse)

TABLE IV

RACIAL/ETHNIC ORIGINS OF U. S. POPULATION*

Group	Number in Thousands	Percent
White	177,784	87.5
Spanish Speaking	10,115	4.9
Black	22,580	11.1
Other	2,882	1.4
Indian	793	0.4
Japanese	591	0.3
Chinese	435	0.2
Filipino	343	0.2
Other	720	0.4

* Source: Bureau of Census, April 1970.

In one study the two largest racial groups were compared in some detail using anthropometric data from the USAF 1965 survey (Long and Churchill). Almost 400 of the subjects classified themselves as Blacks and these were matched with Whites on the basis of age, length of military service, and region of birth. Some 343 reasonable matches were made and the anthropometric data for the matched samples compared. The two groups were almost identical in weights and heights, differing by less than half a kilogram in weight and by about a millimeter in height. Despite this, there are significant differences in the mean values for about three quarters of the measurements. The Blacks have legs, arms, hands and feet which, on the average, are longer than those of Whites; the reverse is true for measurements of the torso. The Blacks tend to have longer heads, wider faces and less body fat. The group means for height are virtually identical but the

Black subjects are, on the average, 2.6 cm longer in leg length and some 3.2 cm shorter in eye-height/sitting.

While individual values for Whites and Blacks overlap to a large extent (partly as a result of greater variability in the White sample), the body size differences cited above are of sufficient magnitude to warrant consideration in the design of systems and equipment to be used by both Whites and Blacks.

Other racial/ethnic comparisons can be made by using the 1966 U. S. Army anthropometric survey data. In this survey the subjects were asked to record their ethnic derivation or national extraction. There were three categories in which national extraction was not otherwise specified: American White (29.4 percent); American Black (14.6 percent), and American Indian (1.5 percent) These categories represent approximately 45 percent of the total sample. The remainder of the sample was self-classified into 37 national origins. It is of some interest to compare these groups in terms of gross body size. Using only the dimensions of height and weight, such a comparison is given in Table V for those groups containing ten or more respondents. The table lists the mean and standard deviation for the total sample and shows the deviation of each group from these values.

The sample sizes of some of the subsets are rather small but they are adequate to indicate the diversity which exists in the various racial/ethnic components of the military population. These differences, which are often quite large, do not in themselves tell the complete story of body size differences.

TABLE V

HEIGHT AND WEIGHT OF RACIAL/ETHNIC GROUPS - U. S. ARMY SURVEY 1966*

Ethnic Group	Number Subjects	Height (cm) $\bar{X}$	Height (cm) SD	Weight (lbs) $\bar{X}$	Weight (lbs) SD
TOTAL SAMPLE	6682	174.52	6.61	159.09	23.35
American White	1960	.58	-.20	-.80	-.24
American Black	982	.02	.04	2.34	.62
American Indian	120	-.08	0.00	-1.97	-1.38
Mexican	113	-4.05	-.32	-2.82	-2.89
Puerto Rican	125	-6.09	-.18	-13.11	-2.82
Spanish	74	-3.48	-.02	-7.83	-1.42
Filipino	13	-7.02	1.40	-8.47	1.04
Hawaiian	10	-1.25	-.40	10.35	4.18
Japanese	26	-5.75	-.55	-9.61	-3.15
English	558	.61	-.20	1.17	.35
Irish	864	.68	-.44	.39	-.41
Scottish	169	.94	-.18	3.32	1.48
Welsh	21	.96	-.42	-1.85	.96
French	273	-.82	-.42	-3.26	1.54
German	1080	.68	-.19	2.44	.88
Austrian	14	-.91	-.37	-4.73	2.02
Polish	218	.43	-.27	1.86	-.69
Swedish	134	1.61	-.18	2.75	-.31
Dutch	147	-.28	-.38	-2.66	-2.29
Italian	319	-2.04	-.47	-.32	-1.80

* Total sample mean and standard deviation with subgroup deviations.

Americans of Japanese ancestory are shown to be, on the average, some 5.75 cm shorter than the total group. This is, of course, a significant difference for design purposes. There is, in addition, a significant difference in proportionality. In a study of Japanese pilots, their average height was found to be equal to the eighth percentile of U. S. Air Force pilots, but their leg length and sitting height were comparable to the first and fortieth percentiles, respectively (Alexander, et al., 1964).

Secular Variation

A final source of body size variability is that associated with the passage of time. It is commonly acknowledged that military recruits are, on the average, taller and heavier than their predecessors although neither the reasons for the increase nor its magnitude are generally understood. First, evidence clearly shows that the physical growth of children is being completed at an earlier chronological age. The world-wide data on age of puberty are amazingly consistent and point conclusively to the fact that girls have experienced menarche and boys puberty at a progressively earlier chronological age. During the past 100 years this change averages three to four months per decade with puberty now being attained two and a half to three years earlier than in the previous century. The result of this is that adult body size is attained at an earlier chronological age. At the turn of the century men reached adult height at approximately 26; now they do so at approximately 23 (Roche and Davila, 1972).

The secular changes in body size are not merely a function of earlier maturity but of greater adult size as well. There has been, in most Western European countries, an increase in male and female adult height of between a quarter and a third of an inch per decade from about 1870 to the present. In general, adults are from two and a half to three and a half inches taller today than they were a century ago (Tanner, 1968).

In the United States, between the years 1910 and 1940, the increase in adult size was approximately a quarter of an inch

per decade and from 1940 to 1960 this rate continued for Blacks but averaged closer to an eighth of an inch per decade for Whites. That such changes and rates of change in adult body size will continue indefinitely seems unlikely; indeed, there is some evidence that the trend toward earlier maturity and increased adult size is leveling off.

Whatever the trend, the secular changes in body size are of sufficient magnitude to be significant in systems and equipment design. As Kennedy (1973) noted, the USAF flying personnel measured in 1967 differed in a number of important respects from those measured in 1950 and, as a result, the "...Seat Reference Point to the cockpit eye line, as specified in MIL-STD-1333 (Cockpit Geometry, Department of Defense, 1969a) and MIL-STD-33574, 5 and 6 (Basic Cockpit Dimensions, Department of Defense, 1969 b, c, d) was increased by 0.5 inches from 31.0 to 31.5 inches. Such dimensions as sitting height, buttock-knee length, and knee height, sitting, to name just a few, are extremely critical in determining the basic vertical and fore-and-aft ejection clearance dimensions in the aircraft cockpit."

Increases in body measurements of USAF fliers documented between 1950 and 1967 are probably attributable, at least in part, to secular increases in body size although this cannot be demonstrated conclusively. The realization that changes in human body size are occurring over time is of importance to those engineers and designers involved in developing systems and equipment for the future.

In summary, it is essential to recognize that the body size of the military population is in a dynamic state and that body size changes must be documented continuously if systems and equipment are to be designed effectively.

CHAPTER IV

CURRENT ANTHROPOMETRIC RESOURCES

The search for new methodology in data acquisition must be based on available resources. We have outlined summaries of several of the more important general resources that will help provide a basis for this search. These resources have been grouped into five categories: the available basic anthropometric data; data providing an understanding of the interrelationships among body size measurements; data relating to the statistical properties of body size; computational procedures available for simplifying and extending the analyses of these data, and non-standard data gathering procedures. The wealth of experience gained by USAF and other anthropologists in actually applying anthropometric data to design and fit problems, while not summarized here, is still another major resource.

Anthropometric Data Resources

Since the closing days of World War II, a great mass of body size data has been accumulated from U. S. military personnel and from individuals in the military services of other countries. The size of the accumulation is suggested by the following partial list of major surveys.

I The United States

A. The Air Force:

survey of flying personnel, 1950, 4063 subjects, 132 measurements; survey of WAF basic trainees,

1952, 852 subjects, 63 measurements; PhotoMetriC survey, 1957, 2191 subjects, 30 direct measurements plus four-view standing and seated photographs from which measurements can be made; survey of 1965, 3868 subjects of whom most (2527) were basic trainees, 792 enlisted men, 549 flying and non-flying officers, 158 measurements; flying personnel survey, 1967, 2420 subjects, 187 measurements; Women of the Air Force survey, 1968, 1905 subjects, 1357 enlisted and 548 officers (mostly nurses), 124 measurements plus 13 measurements repeated over foundation garments.

B. The Army:

survey of World War II dischargees, 1946, ~100,000 male subjects, ~8000 female subjects, 65 measurements; survey of Army pilots, 1959, 500 subjects, 42 measurements; soldier survey (companion to Navy and Marine surveys), 1965-1966, 6682 subjects (including 125 aviators), 70 measurements; Army aviator survey, 1970, 1482 subjects, mostly helicopter crews, 85 measurements.

C. The Navy:

Navy aviator survey, 1964, 1529 subjects, 97 measurements; enlisted survey (companion to 1965-1966 Army and Marine surveys), 1965-1966, 4095 subjects, 70 measurements.

D. The Marines:

enlisted survey (companion to 1966 Army and Navy surveys), 1965-1966, 2008 subjects, 70 measurements.

II <u>European Countries</u>

A. England:

air crew survey, 1970/71, 2000 subjects, 72 measurements; head and face survey, 1972, 500 subjects, 45 measurements; Armoured Corps Servicemen, 1972, 500 subjects, 62 measurements.

B. Germany:

flying personnel survey, 1967-1968, 1466 subjects, 153 measurements.

C. Italy:

NATO survey (with Greece and Turkey), 1961, 1342 subjects from all services, 148 measurements.

D. Greece:

NATO survey (with Italy and Turkey), 1960/61, 1071 subjects from all services, 148 measurements.

III <u>Asian Countries</u>

A. Turkey:

NATO survey (with Italy and Greece), 1960, 912 subjects, 148 measurements.

B. Iran:

ARPA sponsored survey, 1968-1969, 9414 subjects from all services, primarily trainees, 68 measurements.

C. Vietnam and Thailand:

surveys conducted by R. M. White, U. S. Army, 1964, 2129 Vietnamese subjects, 50 measurements, and 2950 Thai subjects, 52 measurements.

D. Japan:

flying personnel survey, conducted with participation of M. Alexander, 1962, 239 subjects, 62 measurements; flying personnel survey, 1971, 2024 subjects, 108 measurements.

E. Korea:

flying personnel survey - an effort by the Korean Air Force to duplicate the USAF 1950 survey, 1961, 264 subjects, 132 measurements.

Numerous other surveys have been conducted.* These include a wide range of valuable small-scale surveys of separate segments of the body, studies of the body in non-classical positions (as, for example, working positions) or encumbered by special flight clothing, investigations of

---

* Many of the special surveys are listed in Reid, 1973; a number of the older surveys are summarized by Hansen and Cornog, 1958; additional foreign studies are covered by Garrett and Kennedy, 1971.

reach capabilities in a multiplicity of directions, and many others. Similarly, a number of surveys of small military groups such as navy divers have been carried out. For general research purposes, however, the surveys listed above seem most useful, and for most of them the original data are stored in the AMRL data bank.

Summary statistics from most of these surveys and for subgroups within a number of them have also been assembled in the AMRL data bank. A list of the dimensions for which statistics are available is given in Appendix 1 to this report. The number of entries for a single dimension ranges from one to a dozen or more.

Non-military data can be valuable in the solution of military problems. However, little appropriate material exists. The most important source of civilian anthropometric data is the Health Examination Survey (HES) conducted in the early 60's by the U. S. Department of Health, Education, and Welfare. Some 15 body dimensions were measured on a nation-wide probability sample of 3581 women and 3091 men in the 18-79 year age range. Most of these dimensions were also measured in the 1967 flying personnel and WAF surveys, and provide a basis for comparing civilian and military body sizes. The HES survey is scheduled to be repeated every 10 years (the data have been gathered for the second group of adults) and should be of help in studying long term trends. The age range covered by the HES data also makes this material useful for studying body size changes with age.

The primary sources of information for solving current USAF sizing and design problems are the 1967 flying personnel and 1968 WAF surveys; a brief summary of the data available from these surveys is given in Table VI.

TABLE VI

BRIEF SUMMARIES OF FLYING PERSONNEL AND WAF SURVEYS

1967 Flying Personnel		WAF	
Total Sample:	2420	Total Sample:	1905
Pilots	1692	Nurses	389
Navigators	693	Other Officers	73
Other	35	Officer Trainees	86
		Enlisted Women	1024
		Basic Trainees	333
Age: 5%ile	22.4 yrs	5%ile	18.3 yrs
50%ile	28.6 yrs	50%ile	21.0 yrs
95%ile	42.4 yrs	95%ile	38.9 yrs

1967 Number	Dimensions Measured	WAF Number
1	Weight	1
9	Skinfolds	4
38	Heights, reaches, long measurements	31
11	Torso breadths and depths	11
12	Torso circumferences and horizontal surface measures	19
23	Limb breadths and circumferences	20
18	Hand and foot measures	6
47	Head and face	29
27	Vertical surface measures	2
	Over foundation garment measures	13

Additional foreign data are expected in the near future from the French. R. M. White is presently obtaining data in Saudi Arabia. With the inclusion of this material in the AMRL data bank, adequate data will be available for handling most, if not all, major efforts to design equipment and

workspace which are to be used jointly by male U. S. military personnel and those of its allies. Designs intended to serve:

a. European allies can be based on U. S., British, German, French, Italian, and Greek data;

b. Near-East allies can be based on Turkish, Iranian, and Saudi-Arabian data;

c. Far-East allies can be based on Japanese, Korean, Vietnamese and Thai data.

Unfortunately, we have virtually no data on foreign female military personnel. Some anthropometrists have been prone in the past to emphasize differences among national averages while overlooking the substantial ranges of values within each national group.

A further weakness in the AMRL data bank is the scarcity of data for ethnic minority groups in the United States. Fair sized groups of Black basic trainees, both male and female, have been measured in USAF and U. S. Army surveys but very little data exist for Blacks over 21 years of age or for Black officers. The situation is similar for Chicanos; for U. S. Orientals, almost no data exist. There is a need for data on these groups both to treat present equipment and fitting problems and to provide a basis for predicting body size patterns which will exist in the USAF if changing military or economic factors alter the rate at which members of these groups enlist.

Resources for Understanding Body Size Interrelationships

Science is based in many ways on observing interrelationships and interactions among many variables. Anthropometry obviously is not a discipline like physics in which the study of observed interactions and variations can be expected to lead to the discovery of causal relationships and quasi-exact mathematical formulations. Nonetheless, anthropometry is a field in which a knowledge of the relationships among the variables with which it deals is important for the solution of its problems, and is even more important for the conceptualization of these problems and the development of approaches to their solutions.

Our knowledge of how body size measurements interrelate has vastly expanded since World War II. In 1946 Randall, Damon, and their colleagues were fully aware of the importance of body size interrelationships in carrying out their work but all they had were some fifty interrelationships classified as either low and useless or as usable (see Figure 3). They had no correlation coefficients, no regression equations, no basis for judging the degree of a relationship between one variable and a set of two or more variables (such as height and weight)--in short, few of the statistical tools of the trade in common use today.

By way of contrast 22 years later, the 1968 WAF report incorporated some 386 pages of material (excluding bivariate frequency tables) based on interrelationships of the dimensions

	Weight	Squatting Diagonal	Anterior Arm Reach	Shoulder-Elbow Height	Span-Akimbo	Bi-deltoid	Sitting Height	Bi-epicondylar (elbows)	Abdominal Depth	Bi-trochanteric	Buttock-Knee	Patella Height	Leg Length (subtractive)
Stature	*	0	*	*	*	0	*	0	0	0	*	*	†
Weight		0	0	0	0	*	0	*	0	*	0	0	†
Squatting Diagonal			†	†	†	†	*	†	0	†	0	†	†
Anterior Arm Reach				†	*	†	0	†	†	†	†	†	†
Shoulder-Elbow Height					*	†	0	†	†	†	†	†	†
Span-Akimbo						0	0	†	†	†	*	*	†
Bi-deltoid							0	0	†	0	†	0	†
Sitting Height								0	0	0	0	*	0
Bi-epicondylar (elbows)									0	0	†	†	†
Abdominal Depth										0	0	†	†
Bi-trochanteric											0	0	†
Buttock-Knee												*	†
Foot Length												*	†

* denotes utilizable correlation
0 denotes low, useless correlation
† denotes correlation not attempted

Figure 3. Schematic Guide to Correlations of Principal Measurements (adapted from Randall, et al., _Human Body Size in Military Aircraft and Personal Equipment_, AAF-TR-5501, 1946).

measured in that survey. It may be worth noting the types of material included in these tables. They include:

1. over 8,000 simple correlation coefficients for age, grip strength, and body size variables. A distribution graph of the coefficients for age and body measurements, taken from the WAF report, appears as Figure 4;

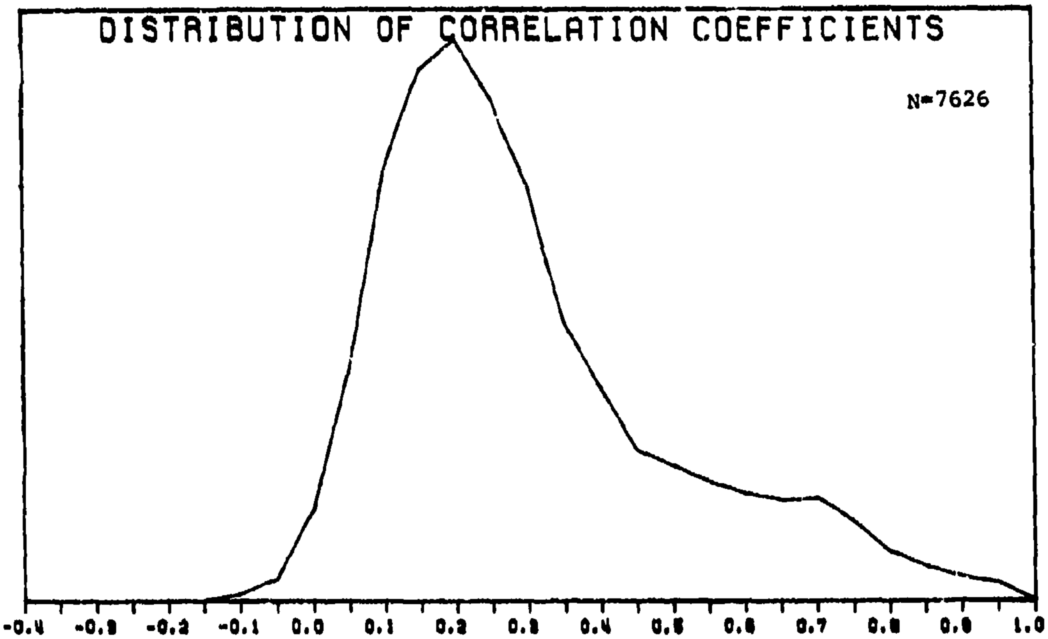

Figure 4. Distribution of Correlation Coefficients.

2. regression equations for estimating one variable from another (equations for all pairs of variables with correlation coefficients in excess of 0.316) and the corresponding standard errors of estimate;

3. estimated values of all other measurements for women of specified heights, weights, and combinations of height and weight;

4. multiple regression equations for estimating other measurements in terms of height and weight, in terms of height and bust circumference, and in terms of ten similar combinations, as well as multiple regression equations for estimating head and face measurements in terms of head length and head breadth and in terms of other combinations of head measurements;

5. two sets of stepwise regression equations. These equations were prepared by a computer program which proceeds as follows for each variable:

> the variable having the highest correlation with the given one is determined; using this variable as the predictor variable, the "best" univariate regression equation is calculated;
>
> the two variables having the highest bivariate correlation are then determined; using this combination, the "best" bivariate equation is calculated;
>
> next, the three variables having the highest trivariate correlation are determined, and so forth.

The WAF report provides equations based on one to eight predictor variables; the equations are accompanied by the multiple correlation coefficients and standard errors of estimate. The second of the two sets of equations differs from the first set only in that height and weight were automatically included as predictors for all other variables;

6. tables of partial correlation coefficients measuring the relationship between pairs of variables for women of the same weight, for women of the same height, for women of the same height and the same weight, and for women of the same height, the same weight, and the same age;

7. analysis of the magnitude of the correlations between various anatomically similar groups of measurements.

Similar material, including over 16,000 correlation coefficients, is available for the 1967 flying personnel survey data. The complete correlation matrix for the 1950 flying personnel survey is also available and a full presentation of the correlation coefficients has been included in the published reports of several of the surveys listed above.

Correlational data lend themselves to many types of analysis. A recent factor analysis study of race- and sex-specific anthropometric data from United States, European, and Asian sources (Churchill, 1974) is an example of the sort of study which adds to our understanding of body size data.

None of the aforementioned data is presented here since the substance of the material is not particularly relevant to our present purposes. What is important is that great quantities of such data are available and that much more material can be created as the need arises.

Statistical Properties of Body Size Data

If one is to make optimum use of available data, a knowledge of its statistical properties is usually required.

A major assumption which undergirds anthropometric data handling is that most body size data for healthy individuals of military age is, in the jargon of the statistician, approximately multivariate normal. An important corollary of this assumption is that the information contained in the original data is completely contained in the basic summary statistics--the means, standard deviations, and correlation coefficients.

Multivariate normal variables are linearly related, i.e., their relationships can be expressed in the equations of the form $Y=A+BX$, $Y=A+B_1X_1+B_2X_2$, $Y=A+B_1X_1+...+B_kX_k$. These relationships are homoscedastic; that is, the variation around the regression line or plane is independent of the values of the predictor variables. This means, for example, that the standard deviation of head breadth is, at least approximately, the same for long-headed men, medium-headed men, and short-headed men.

The assumption of approximate multivariate normality makes it possible to compute, without recourse to the original data, such material as:

1. percentile values obtained by adding or subtracting multiples of the standard deviation from the mean;

2. percentile values of computed variables obtained by adding or subtracting two or more of the original variables;

3. the proportion of a population of values which lies within an interval of values of one variable or within any combination of intervals for a group of variables;

4. the proportion of individuals who will be disaccommodated by any univariate or multivariate design;

5. the mean, standard deviation, and percentiles for any variable for any subset of the original population based on one or more anthropometric measures;

6. estimates of the mean, standard deviation and percentiles for the total population based on data from restricted or truncated samples;

7. estimates of the sampling error for any of these statistics from microcosm samples, plateau samples, and other probability samples.

Another significant fact about most anthropometric measures (weight and skinfold measures excluded) is that the coefficients of variation are (1) fairly small and (2) relatively the same for anatomically similar dimensions. A consequence of the small size of the coefficients of variation is that the computations listed in 1-7 above can usually be done for non-linear functions (indices, etc.) of the original variables as well as for linear ones (Churchill, 1963). The second characteristic of the coefficient of variation provides a basis for estimating standard deviations for unmeasured variables. This can be important in designing sampling procedures for variables, since the sampling errors for a variable are closely related to the variable's standard deviation.

The fact that most anthropometric data have an approximately multivariate normal distribution with small coefficients

of variation has two important implications relevant to the development of sampling strategies:

1. the theoretical basis exists for mathematically evaluating various sampling procedures, for estimating the sampling errors associated with any procedure and sample size, and for providing a basis for selecting the optimum procedure;

2. the possibility clearly exists for computing design values for sub-ranges of a population on the basis of the data for the entire range. This is perhaps the most significant concept in this section since its application would enable us to design, say, a narrow-long face mask using the full range of facial measurements rather than just the data obtained from a few prospective wearers of this size. If this is done, the sampling error of our design values would be related to the size of the entire sample and not that of a small subgroup; the sample size needed to provide adequately small sampling errors would thus be substantially reduced.

Work remains to be done in the area of the statistical properties of body size data. Although the word "approximately" will never be completely removed from the phrase "approximately multivariate normal," there remain a number of points concerning the nature and extent of the approximations on which we could use additional information.

Resources Based on Computational Procedures

It is unnecessary to belabor the extent to which the modern computer is a major resource in the handling of body

size data. The XVAL and EDIT programs, developed under AMRL sponsorship, are now widely used to isolate and eradicate the inevitable recording and processing errors contained in great quantities of survey data, and to provide clean data without which all later analyses would be less precise and useful. The stepwise correlation program whose complex computations are described above is clearly a child of the computer. Artificial bivariate and proportions-disaccommodated programs are examples of how information which previously could be obtained only by tedious extraction from often obscure tables can now be quickly and painlessly obtained in a more useful form. Programs such as the one which draws the ellipses shown in Figure 2 (Chapter III), without generating new data, present old material in a form which facilitates a better understanding of it. Reference was made earlier to the voluminous amount of correlation material incorporated in the 1968 WAF report and to the one-page table of 50 or so correlation values which appeared in a 1946 AAF technical report. The time needed by the computer to generate the entire 386 pages of WAF correlational material was less than that required by the data processing machinery of two decades earlier to produce a single point on the AAF table.

No information can be considered genuinely valuable unless its potential value exceeds the cost and the delays incurred in obtaining it. A major contribution of the computer has been to vastly increase the range of information which meets this criterion.

Non-standard Data Gathering Procedures

Unfortunately, most of the resources in the area of non-standard data gathering are negative. A wide variety of procedures has been developed, utilized for varying periods of time, and then abandoned, bequeathing to us little more than the knowledge that we should pass them by. The U. S. Navy had a measuring rig which they abandoned when it proved riddled with all sorts of sources of error. The AMRL contourometer surely produced far more anguish than useful data and has long been retired. The PhotoMetriC system used for a USAF survey in 1957 did produce a modicum of data, some of it unique, but it is doubtful that anyone has ever seriously suggested the system be used for another survey. Stereophotography is currently being touted as the successor to standard anthropometry, but it is a very expensive, slow procedure.

Photography has been widely used as a substitute for direct measurement, often with indifferent results. One source of difficulty has been that many of these photographs were taken primarily for somatotyping rather than for measurement. Another source of difficulty has been the practice of using total body photographs for measuring small segments which may represent only two percent or so of the negative's length. Little evidence exists in the literature to suggest that careful planning and experimentation have preceded many photographically oriented surveys. We believe, however, that photography, carefully planned and executed, has real potential

for surveys designed for specific goals and we have recently accepted responsibility under an AMRL research contract to demonstrate that this is so.

Of all the non-standard methods of gathering anthropometric data, the simplest and, it would appear, one of the most potentially useful ones, is that of simply asking individuals how tall they are and how much they weigh. While these questions have long been asked of military personnel, little has been done until recently to ascertain the reliability of the answers. Data from seven recent military surveys relating to this subject are summarized in Table VII. Table VIII, reproduced from the WAF report, illustrates the relationship between the measured and reported heights and weights obtained in that survey.

For 15 of the survey samples and subsamples, correlation coefficients (r's) are listed in Table VII. The median of the measured-reported weight correlations is about 0.96 and that of the measured-reported height correlations is about 0.94, indicating quite close relationships between the measured and reported values. These correlations are probably higher than the test-retest correlations we would find for a great many standard anthropometric measures. For the 1967 survey, actual weight can be more accurately estimated from reported weight than from any of the 185 direct measurements; height can be more accurately estimated from reported height than from any but three direct measurements (cervicale, acromial, and suprasternale heights).

TABLE VII

COMPARISONS OF MEASURED AND REPORTED HEIGHTS AND WEIGHTS

I. U. S. Army Survey - 1966 (N = 6082)

	Height		Weight	
Measured	$\overline{X}$ = 68.7	SD = 2.6	$\overline{X}$ = 159.1	SD = 23.4
Reported	$\overline{X}$ = 69.8	SD = 2.7	$\overline{X}$ = 161.4	SD = 23.3
	r = .935		r = .951	

	Reported-Measured Heights		Reported-Measured Weights		
Basic Trainees	Δ = 1.0	r = .932	Δ = 0.8	r = .963	N = 2639
Infantrymen	Δ = 1.2	r = .939	Δ = 3.3	r = .941	N = 3428
Armored Personnel	Δ = 1.3	r = .932	Δ = 3.8	r = .955	N = 488
Aviators	Δ = 1.1	r = .934	Δ = 2.4	r = .948	N = 125

II. U. S. Navy Enlisted - 1966 (N = 4095)

	Height		Weight	
Measured	$\overline{X}$ = 69.0	SD = 2.6	$\overline{X}$ = 157.8	SD = 23.3
Reported	$\overline{X}$ = 69.9	SD = 2.7	$\overline{X}$ = 158.8	SD = 23.9
	r = .937		r = .975	

III. U. S. Marines Enlisted - 1966 (N = 2008)

	Height		Weight	
Measured	$\overline{X}$ = 68.7	SD = 2.5	$\overline{X}$ = 160.2	SD = 19.7
Reported	$\overline{X}$ = 70.2	SD = 2.6	$\overline{X}$ = 163.9	SD = 19.3
	r = .919		r = .955	

IV. U. S. Army Aviators - 1970 (N = 1482)

	Height		Weight	
Measured	$\overline{X}$ = 68.7	SD = 2.5	$\overline{X}$ = 171.2	SD = 23.8
Reported	$\overline{X}$ = 70.1	SD = 2.6	$\overline{X}$ = 170.9	SD = 21.8
	r = .943		r = .965	

TABLE VII (continued)

V. USAF 1965 Survey

Basic Trainees (N = 2653)

	Height		Weight	
Measured	$\bar{X}$ = 68.9	SD = 2.5	$\bar{X}$ = 151.5	SD = 22.5
Reported	$\bar{X}$ = 69.6	SD = 2.7	$\bar{X}$ = 153.2	SD = 22.5
	r = .943		r = .982	

Officers (N = 549)

	Height		Weight	
Measured	$\bar{X}$ = 69.7	SD = 2.5	$\bar{X}$ = 171.4	SD = 20.4
Reported	$\bar{X}$ = 70.3	SD = 2.5	$\bar{X}$ = 171.3	SD = 20.0
	r = .967		r = .981	

Enlisted (N = 789)

	Height		Weight	
Measured	$\bar{X}$ = 68.8	SD = 2.7	$\bar{X}$ = 162.0	SD = 24.8
Reported	$\bar{X}$ = 69.6	SD = 2.7	$\bar{X}$ = 163.4	SD = 23.8
	r = .958		r = .977	

VI. USAF Flying Personnel - 1967
(N = 2420)

	Height		Weight	
Measured	$\bar{X}$ = 69.8	SD = 2.4	$\bar{X}$ = 173.6	SD = 21.4
Reported	$\bar{X}$ = 70.6	SD = 2.4	$\bar{X}$ = 173.6	SD = 19.7
	r = .956		r = .974	

VII. Women of the Air Force - 1968

Total (N = 1903)

	Height		Weight	
Measured	$\bar{X}$ = 63.8	SD = 2.4	$\bar{X}$ = 127.3	SD = 16.6
Reported	$\bar{X}$ = 64.8	SD = 2.4	$\bar{X}$ = 125.4	SD = 15.8
	r = .961		r = .973	

Officers (N = 547)

	Height		Weight	
Measured	$\bar{X}$ = 64.1	SD = 2.4	$\bar{X}$ = 131.5	SD = 18.5
Reported	$\bar{X}$ = 65.1	SD = 2.5	$\bar{X}$ = 130.6	SD = 17.2
	r = .970		r = .978	

TABLE VII (concluded)

(VII. Women of the Air Force - 1968)

Enlisted (N = 1356)

	Height		Weight	
Measured	$\overline{X}$ = 63.7	SD = 2.3	$\overline{X}$ = 125.5	SD = 15.4
Reported	$\overline{X}$ = 64.7	SD = 2.4	$\overline{X}$ = 123.3	SD = 14.7
	r = .957		r = .970	

There is in all these data evidence of a tendency to overestimate one's height. The mean differences were fairly consistent; of the 15 listed differences, 10 fell in the 0.8 - 1.2 inch range.

All but one comparison based on male surveys showed reported weights generally above actual ones; for the women the reverse was true. Weight differences for men ranged from an underestimate of 0.3 pounds to an overestimate of 3.8 pounds. The three women's figures fall in the range of one- to two-pound underestimates. Considered relative to the standard deviations for weight, these differences are not large. Anecdotal evidence from members of several of the survey teams suggests, in fact, that the weight differences could be accounted for by the work and eating patterns of the survey subjects at the time they were measured.

The "reported" data presented in Table VII were all obtained by asking survey subjects their heights and weights immediately prior to their being measured. The question of whether people will give more accurate answers knowing that their answers will

TABLE VIII

BIVARIATE TABLES OF REPORTED AND MEASURED HEIGHTS AND WEIGHTS

(WAF Survey Data--The Total Series)

Height as Reported by Subjects (inches)

Height as Measured (cm)

	58.00	59.00	60.00	61.00	62.00	63.00	64.00	65.00	66.00	67.00	68.00	69.00	70.00	71.00	72.00	73.00	74.00	TOTALS
183.25																	1	1
181.25															1			1
179.25													1	4	4			9
177.25												1	6	4	2	1		14
175.25												5	8					13
173.25											8	35	9	1				53
171.25										5	45	25	7					82
169.25								1	3	35	72	12		1				124
167.25								7	40	94	45	1						187
165.25							1	25	101	50	6							183
163.25						2	18	108	101	10	2							241
161.25			1		1	21	121	104	11	1								260
159.25					6	65	114	24	2									211
157.25				6	46	100	36	2										190
155.25			1	14	100	40	5											160
153.25			8	35	40	5												88
151.25			26	27	5	1												59
149.25			16		1													17
147.25		3	5															8
145.25	1		1															2
TOTALS	1	3	58	82	199	234	295	271	258	195	178	79	31	10	7	1	1	1903

SUMMARY STATISTICS

	Mean	Std. Dev.	R
Measured Height	162.11 cm (63.82 in)	6.00 cm (2.36 in)	0.961
Reported Height	64.81 in (164.62 cm)	2.43 cm (6.17 in)	

Weight as Reported by Subjects (lbs.)

Weight as Measured (lbs.)

	84.00	89.00	94.00	99.00	104.00	109.00	114.00	119.00	124.00	129.00	134.00	139.00	144.00	149.00	154.00	159.00	164.00	169.00	174.00	179.00	184.00	189.00	194.00	TOTALS
200.00																						1	1	2
195.00																						1	1	2
190.00																				1			1	2
185.00																		1	1	2	3			7
180.00																1				2				3
175.00														1				3	2	1				7
170.00														2	2	1	2	7						14
165.00														1	3	6	5	2						17
160.00												1	1	3	7	14	4							30
155.00												3	7	15	20	3								48
150.00											1	8	25	34	2	1								71
145.00										1	16	44	56	5										122
140.00									1	12	51	60	18											142
135.00								1	7	69	83	19	2											181
130.00								17	72	107	33	2												231
125.00						1	7	84	104	39	2													241
120.00					2	5	53	117	42	4														221
115.00					2	17	133	35	4															209
110.00					24	77	48	3																152
105.00			1	15	71	24	2																	113
100.00		2	8	36	12	2		1																61
95.00			12	9	1																			22
90.00		3	1																					4
85.00	1																							1
TOTALS	1	5	22	60	112	146	243	238	232	230	106	137	109	61	14	26	11	19	5	6	3	2	3	1903

SUMMARY STATISTICS

	Mean	Std. Dev.	R
Measured Weight	127.26 lbs	16.58 lbs	0.973
Reported Weight	125.40 lbs	15.83 lbs	

be quickly checked than they would have done otherwise has been raised. One further set of data provides evidence on this point.

In October 1966, a world-wide survey of the USAF, which covered a 13% sample of all non-general officers on duty anywhere in the world except in active fighting areas, included questions about the height and weight of the respondents. Almost 12,000 responses, slightly fewer than half from officers on flying status, were received. Similar data were obtained for enlisted men. While we will report here only on the flying personnel data, it is worth noting that this survey constitutes the only source of height and weight data for large groups of non-flying officers and enlisted men beyond basic training. The data were also available by command and age breakdowns.

For the 5,700 officers on flying status, the results were:

Reported weight: $\bar{X}$ = 173.1, SD = 18.8, Median = 172.3 lbs
Reported height: $\bar{X}$ = 70.5, SD = 2.4, Median = 70.5 in

These values agree exceedingly well with the results of the 1967 survey taken six months later (mean reported weight 173.6 pounds, mean reported height 70.6 inches). Among the subjects of this survey were 196 men who had also been subjects of the world-wide sample survey cited above. For these men, we have three sets of heights and weights:

1. values reported on a "mail" questionnaire with no immediate likelihood of direct measurement (October-reported);

2. values reported four-five months later just prior to being measured (winter-reported);

3. actual measured values (winter-measured).

We obtained the following results:

	Weight		Height	
October-reported	$\bar{X}$ = 172.4	SD = 18.2	$\bar{X}$ = 70.5	SD = 2.5
Winter-reported	$\bar{X}$ = 174.2	SD = 19.4	$\bar{X}$ = 70.6	SD = 2.4
Winter-measured	$\bar{X}$ = 173.9	SD = 20.4	$\bar{X}$ = 69.9	SD = 2.5
r (1, 2)	= 0.949		0.904	
r (1, 3)	= 0.925		0.888	
r (2, 3)	= 0.971		0.954	

A comparison of the means and standard deviations seems to indicate that answers can be obtained on "mail" surveys which are very similar to those obtained by asking the same questions immediately prior to actual measurement. While all the correlation coefficients just reported are high, the October-reported correlations with winter-measured are clearly lower than the winter-reported correlations with winter-measured. The difference in the weight values may be due, in part, to actual changes in weight, but this can hardly be true of the heights.

We raise one final question about reported heights and weights: how well could they serve in estimating other body dimensions? An answer to this question is given in Figure 5 in which the multiple correlations with reported weight and reported height are plotted against those with measured weight and measured height for all the measured variables in the 1967 survey except the skinfolds and head and face measurements.

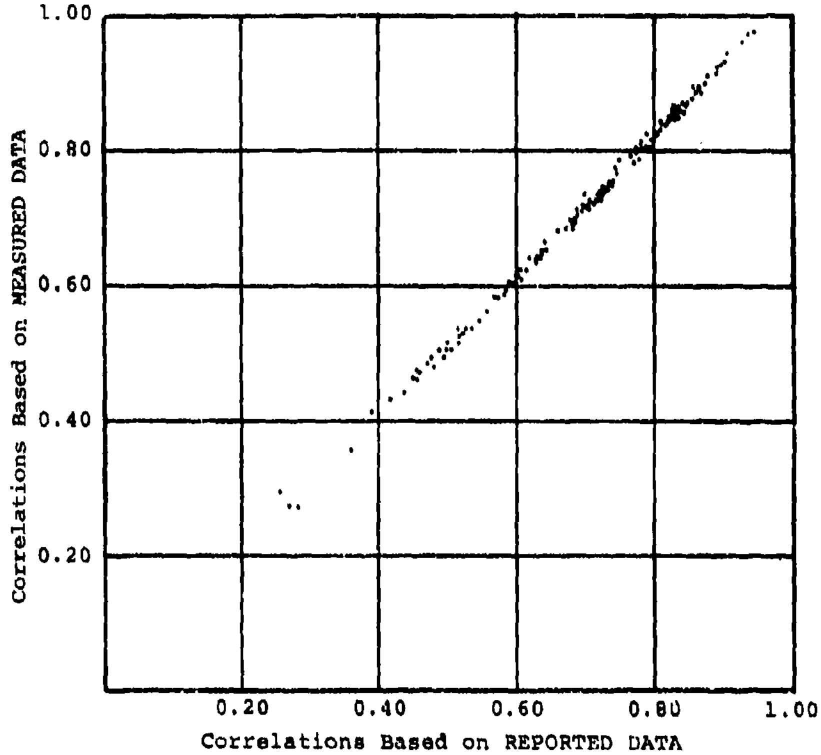

Figure 5. Multiple Correlations for Measured Height and Weight vs. Those for Reported Height and Weight (1967 survery data--skinfolds and head-face data excluded).

Clearly there is substantial agreement as there is, in fact, among the measured height and reported height correlations and among the measured weight and reported weight values. In a few cases the simple correlations with reported heights and weights are higher than the corresponding correlations with measured heights and weights. In no case, however, are the multiple correlations based on the measured values lower than those based on the reported ones. The median absolute differences for all three sets of comparisons are in the neighborhood of 0.02.

Two non-military studies in this field are worthy of brief note. In the first, workers in several Dayton and

Cincinnati area factories were supplied with a paper tape measure and asked to report their heights, sitting heights, chest circumferences, and weights. Within a day or two they were measured at their places of employment. As with the military series, agreement between reported and measured heights and weights was good, and agreement for chest circumference was quite satisfactory. The reported data for sitting height, however, proved to be so inaccurate as to render it almost worthless. The second study, recently reported by the Federal Aviation Administration, shows major discrepancies between measured and reported heights. Their report, however, leaves little doubt that the major error sources were a faulty questionnaire and the absence of any basis for classifying ambiguous data.

The material presented in this section suggests that reported height and weight data, even those obtained by "mail" surveys, have considerable potential for designing sample plans and for matching samples and populations. They can also be useful as a basis for translating values obtained from one population (e.g., flying officers). to a second population (e.g., non-flying officers). The utility of reported measurements might be even further increased by devoting a modest effort to improving the basic questions and designing one or two additional questions (perhaps related to clothing sizes) which would provide a basis for clarifying ambiguous answers.

CHAPTER V

SAMPLING DESIGNS

Collectors of anthropometric data often overlook the fact that there is a wide variety of sampling schemes, each with its own strengths and flaws. We shall describe here a number of these plans and offer some evaluation of each. On the basis of these evaluations we make a single generalization, to wit, that no sampling plan will be best for all types of data collection and that for any particular survey a variety of plans should be scrutinized to determine the one best for the survey at hand.

Random - Quasi-quota - Microcosm Sampling

We have grouped here all the schemes designed to obtain a sample which is representative of the population under study. Most anthropometric surveys and all major USAF surveys have used such sampling. Usually the word "random" is associated with this type of smapling but, as strictly defined by statisticians,*

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* Statisticians define a random sampling plan as one in which, a priori, every individual has an equal chance of being selected, and in which an individual's chance of being selected is independent of every other individual's chances. The second condition keeps a survey such as the USAF world-wide survey, referred to in the previous chapter, from being truly random. In this survey each individual with a serial number ending in any one of certain combinations was included. Under this plan the first segment of this definition was satisfied since each individual did have an equal chance, ahead of time, of being included. However, the second segment was not satisfied since two men with serial numbers ending in the same digits would both be included or both excluded. However, this condition would seem to be of little importance in sampling from populations as large as the major segments of the USAF.

it is doubtful whether true random sampling has ever been, or ever will be, used in military surveys. This is not to say, of course, that anthropometrists must abandon the effort to secure data broadly representative of the population as a whole. Major surveys, such as the 1950 and 1967 surveys of flying personnel, were organized on the basis of quasi-quotas to include men of different commands, different ranks, and different ages, stationed at bases throughout the country. We have presented evidence, based on reported heights and weights, that in the later survey, at least, there was a close similarity between the entire flying officer population and the survey sample. This kind of sample-population matching can, however, be done only when the sample is, by standards we will later develop, unnecessarily and expensively large.

Comparable results can usually be achieved by construction of a microcosm sample which can be defined as a group of subjects selected to correspond to the larger population in a limited number of significant characteristics such as height, weight and age. That is, the <u>distribution</u> of values in the microcosm sample makes it a scaled down version of the larger population in terms of the significant characteristics.

Microcosm samples can be tied in several ways to the population from which they are chosen or to a population very like it providing we possess some information about the population. If, for example, reported heights and weights of the USAF flying personnel are known, a microcosm sample could be selected to match these values. One method of doing this would be to

divide the bivariate distribution of these variables into a number of boxes, each representing a proportion of the total population. A sample would then be drawn by selecting appropriate numbers of individuals from each of the boxes. A second method, useful if potential subjects with known reported heights and weights are available, is to select a sample which agrees with the population statistics (means, standard deviations, and correlation coefficients) for these variables.* When the latter method is feasible it is preferred to the former because the former, while providing a sample likely to agree closely with the population with respect to mean values, will usually give samples with standard deviations smaller than those of the population.

If limitations of time, location and available subjects prevent construction of a microcosm sample which corresponds exactly to the larger population, it is possible to scale the results up or down as needed. This is done by adjusting the mean values of all measured variables by means of regression equations. Thus, if the goal is a sample similar to a population with known reported heights and weights, it is possible after the data have been collected to compute regression equations for all other variables in terms of these two, and to replace the sample mean values with the values obtained by putting the desired height and weight values in these equations. This approach should considerably reduce the sampling error for

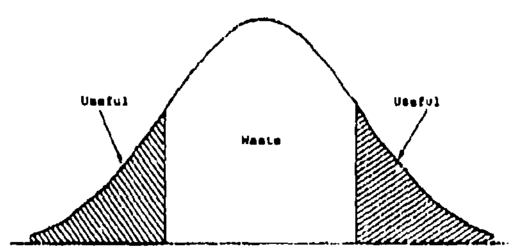
* Computer programs have been prepared for the use of either of these approaches.

the mean values for those variables highly related to height and weight. It will, however, not affect the sampling error of the standard deviation.

Statistical analyses of data from microcosm sampling will ordinarily by simpler than those of data from other kinds of samples and will involve fewer assumptions. Further, by making reasonable statistical assumptions, the data from such samples can be used for estimating design values for every size. This can also be achieved with the data from other types of samples, but it is usually simpler to do this from microcosm samples.

Having expounded at some length on the advantages of microcosm sampling, it must now be said that this can be an inefficient and wasteful type of sample selection for surveys aimed at seeking solutions to certain specific problems.

There are two broad categories of design problems in which body size data play a major role. One of these is the single-size design problem where, with respect to one or more dimensions, the primary concern is that an item be big enough for a big man and small enough for a small man. There will be occasions in which the genuinely useful data for such a design will come from the lowest and highest, say, 10% of a microcosm sample, with the remaining 80% being of almost no direct value.



Better information would undoubtedly be provided by a sample consisting of twice as many men in the two tails of the distribution--and none in the middle. Occasionally, only one end of a distribution is important; one may well ask, for example, what the 3000 men whose height was measured as 70 inches or less in the 1950 survey tell us that is of value in determining doorway heights or bed lengths that isn't better told by the considerably fewer men 71 inches tall or taller. It is true, of course, that we would not ordinarily conduct a survey specifically to determine the proper height of doorways; it is also true that if we accept the premise that heights are normally distributed, we can estimate the proper upper design value for such heights even from a sample with the upper end of the distribution missing.

The second major type of design problem involves multi-size designs. A simple example is that of the six-size helmet liners used by the USAF. For this, the survey sample was divided into six groups on the basis of head circumference. The data for each of these groups were then analyzed separately and the design values obtained. Similar sizing procedures were used for the various items (partial pressure suits, etc.) sized on the basis of the height-weight sizing system and for the oral-nasal face mask, though the size-subgroups were based in these instances on two variables rather than on one.

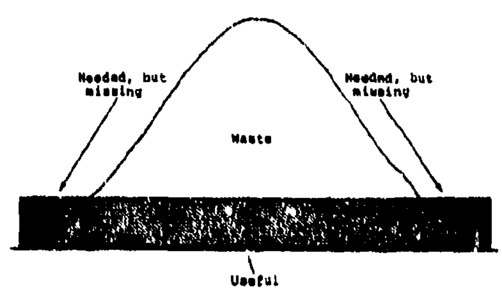
For this type of data analysis, microcosm sampling is simultaneously inadequate and wasteful. Consider, for example, the use of the 1967 survey data in the design of the helmet

liners. Since there is some pooling of the data in estimating a common within-a-size standard deviation, subsamples of 200 each may be assumed to be of adequate size for each liner size. Thus:

Six-Size Head Circumference System
(Based on 1967 Data)

Size	Range (cm)	Required Sample	Actual	Deficit	Excess
I	53.85-55.15	200	98	102	
II	59.15-56.45	200	485		285
III	56.45-57.75	200	801		601
IV	57.75-59.05	200	675		475
V	59.05-60.35	200	286		86
VI	60.35-61.65	200	60	140	
		1200	2405	242	1447

For two of the six sizes, the available data fall far short (<50%) of the necessary sample size, suggesting the potential for serious design error. On the other hand for the four remaining sizes, the samples are anywhere from 43% to 300% too large. Roughly 60% of the entire sample was--relative to this design system--superfluous.



The samples for the extreme sizes, in addition to being too small, are seriously biased. The sample for size 1, for example, includes three times as many subjects above the

midpoint of the size interval as are below it, and the resulting design values will be ones appropriate for a range of head circumferences of about 54.10-55.40 cm rather than 53.85-55.15 cm.

Plateau Samples

Plateau sampling was introduced, without being named, in the preceding paragraphs. A sample consisting of 200 men in each of the six size categories for head circumferences would be a plateau sample. The major drawback to be considered here is that a platoau sample will be a plateau sample only with respect to a single variable. Our head circumference sample would, unfortunately, not provide equal numbers of subjects for a head length or a head breadth sizing system. One could devise a sampling scheme based on the initial selection of the smallest group of individuals from which a head circumference plateau sample, a head breadth plateau sample, and head length sample could be chosen but this seems an unnecessarily complicated approach.

Plateau sampling is probably best suited to dealing with "latent data" by which we mean data that can be ascertained from available records (generally photographs) but which, because of the work involved, are not read until needed. Head circumference was measured directly in the 1957 PhotoMetriC survey and is available on the magnetic tape record of this survey. If data for designing a head circumference sizing system were now wanted, it would be a simple procedure to have

the computer select an appropriate plateau sample from the men included in this survey and then make the necessary measurements on their photographs. If it were subsequently decided to use these same measurements for a head length sizing system, the computer could select the relatively few additional subjects whose photographs would need to be measured.

Plateau sampling also has potential value in selecting subjects for anthropometric research, particularly when the statistical nature of the relationships among the background and experimental factors are not well established. Thus, for example, in a study in which age is an important factor, an experimental panel might well be chosen to include equal numbers of subjects within each five-year interval over the desired age span.

Stratified Samples

In conducting the 1967 survey a conscious effort was made to obtain navigators as well as pilots, students in pilot training programs as well as students at the staff school at Maxwell Air Force Base, and subjects in a variety of other strata. This was done for the purpose of creating a sample which closely resembled the population. True stratified sampling is based on a system of subsamples designed to minimize the sampling error of the resulting statistics; to achieve this, the sizes of the subsamples are usually not proportionate to the relative sizes of the strata in the population. Sampling schemes of this type are most useful when the differences between the strata are

large, whereas in most USAF anthropometry the within-group differences, rather than the between-group differences, are the large ones. The major exception to this is the difference between male and female groups. We can think of the 1967 and the WAF surveys as constituting a single, stratified sample of USAF personnel, noting that the sample sizes for the two strata are roughly equal and do not reflect the relative numbers of men and women in the USAF.

U-Shaped Samples

When analysis of a design problem makes it clear that a design which accommodates both small and large men will of necessity accommodate those in between, it makes sense to sample only small and large men. This may be particularly true for arm-reach envelope studies, for example, where the sample size is severely restricted because of the considerable time required to obtain the data from each subject. In this case, useful results more than compensate for the difficulties of selecting subjects and obtaining information.

W-Shaped Samples

When a design problem depends basically on only the largest and smallest men, it may still be of interest to include representatives of the medium-size potential users in the research sample. One might in such a case choose a sample like the following:

Height (in.)	Number of Subjects
64 1/4 - 66	25
69 1/4 - 70 1/2	25
73 3/4 - 75 1/2	25

Such a sample, based on the extremes and the middle can be described as a W-sample.

L-Shaped Samples

Other design problems may relate only to men at one extreme of the population. Such problems are illustrated by the difficulties recently experienced by large pilots at Hill Air Force Base in wearing the SRU-21/P survival vest/body armor along with heavy flight clothing. A study of this problem was conducted at Wright-Patterson Air Force Base using as subjects the available SAC flight personnel who weighed over 200 pounds. Samples of this type with data from only a narrow range of values (209 to 244 pounds in this case) are designated as L-shaped.

Other types of sampling strategies do exist. The more complicated the strategy, the more complicated the problem of selecting the subjects may be and, for some strategies, the more complicated the analysis may be. For studies requiring considerable time per subject, however, such complexities may be worth facing. For any type of study, the feasibility of each potential sampling plan should be evaluated in terms of its statistical efficiency and its ease and simplicity of use.

CHAPTER VI

USAF ANTHROPOMETRIC NEEDS AND SURVEY STRATEGIES

The USAF needs for basic anthropometric data take a variety of forms. The most appropriate way of gathering a particular body of data usually depends on the use to which it will be put. Thus it may be worthwhile to consider, first, the nature of the needs and then explore how they may best be satisfied.

1. There is need for a large body of general data, covering many dimensions and all parts of the body, based on subjects of various ages, socio-educational groups, ethnic backgrounds, and both sexes. These data are needed for an understanding of the statistical nature of body size measurements and of the interrelationships among the dimensions of the body. The primary function of these data is to facilitate an understanding of anthropometric problems and to aid in developing approaches to their solutions.

2. From time to time, the need for data to solve a specific design problem arises. Ideally, these data should accurately portray current and future USAF personnel who will use or otherwise be affected by the item being designed.

3. Information is required to furnish a sound basis for estimating accurately the proportions of USAF personnel who

fall within specified ranges of selected anthropometric measures, such as weight, stature, and sitting height.

4. There is need for data with which to follow secular trends.

5. Data must be assembled for studying the relevance of body size and body proportions to the outcome of low-probability incidents, such as in-flight ejection.

6. Information is needed to study variations among major groups within the USAF, such as differences between Oriental and Caucasian faces or between male and female reach envelopes.

Understanding the Statistical Nature of Body Size Data

The first of these broad groups of needs is, fortunately, rather well satisfied by the survey data already available. Not all questions we could ask about the statistical nature of body size data have been answered and some probably never will be. Many of these unanswered questions involve the tails of the statistical distributions, the very small men and the very large ones. Massive surveys, such as the 100,000+ survey of men leaving the Army in 1946, are not likely to prove useful in answering the questions since the solutions depend on the analysis of very small variations requiring a level of measuring and sampling precision not likely to be achieved in massive surveys. There remain, however, many questions for which the answers can be obtained from the available data.

Data for Specific Design Problems

It is difficult to imagine any major design problems for which the basic body size data are not already available. With the passage of time, it may be desirable to update some of this information and we will suggest how best to do this in a subsequent portion of this report. However, most of the already-existing basic data for multi-size designs will continue to be useful unless substantial shifts in body proportions take place. Although mean heights and weights do increase with the passage of time, there is no evidence to suggest that a piece of personal equipment which fits a man of 175 pounds and 70 inches a decade ago will not fit a man of this size today or a decade from now.*

We would recommend against conducting any more massive all-purpose surveys designed to describe in detail the entire human shape from head breadth to instep length. Given the already available data, any further such undertaking would be unnecessary, inefficient and impractical. Additional surveys which will be needed from time to time should have a specific purpose to serve as, for example, the gathering of additional head and face data to meet new mask design requirements.

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* A few years ago Sears Roebuck and other mail order firms began sizing boys' clothing on the basis of a re-analysis of data from the mid-thirties. The resulting drop in returned merchandise indicated that even for children - a far more heterogeneous and rapidly changing population than flying personnel - clothing sized on dimensions like height and weight can properly fit the descendants of the survey sample.

Task-oriented surveys are almost certain to be concerned with a single portion of the body at a time. While it is possible that the need for new face data and new foot data might arise at the same time, little, if anything, would be gained from an anthropometric point of view by obtaining these data from the same men. The men who wear masks will, of course, wear shoes, but they will choose the appropriate size of one without regard to the other. It is, in addition, difficult to imagine a combined survey contributing anything useful we do not already know about the interrelationships of face and foot dimensions.

One element essential to body size surveys is a ready supply of appropriate subjects. Since the most critical USAF design problems usually concern flying personnel, the most appropriate subjects for our surveys are USAF officers, men who often have pressing time commitments and are, thus, prone to annoyance if measuring sessions become lengthy. It has been found that an hour is the maximum time which can reasonably be demanded for the actual measuring process; this, in turn, means a total of one-and-a-half to two hours away from an officer's normally scheduled activities.

If the survey design requires that a large number of measurements be made on each man, pressure to complete this process in a brief period may seriously hamper efforts to carry out the measuring with maximum care and precision. To make 180 measurements (fewer than were made in the 1967 survey) in one hour provides exactly twenty seconds per

measurement. It is true that many studies have shown that the accuracy with which a task is conducted does not necessarily increase as the time spent doing it is increased. Nonetheless, there is a minimum time required for performing each measurement properly. Without careful posing and careful checking of the tape or anthropometer, results cannot be relied upon.

New surveys will presumably be concerned mainly with new and not-as-yet standardized measurements. In contemplating future surveys, Dr. S. M. Garn (1973) has proposed that where a choice of techniques and procedures exists, decisions should be based on comparative studies of inter- and intra-measurer reliabilities. Again, the human resources for large numbers of such studies are likely to be severely limited.

We suggest that surveys of body size dimensions be limited to about 40 measurements which should be adequate for a survey oriented to a particular task. This number is large enough to include a few measurements which would serve to tie the sample in with prior samples, and small enough to assure the sort of thorough planning and careful execution needed to provide data of high accuracy.

"Head-Count" Data - Tariffs and Proportions-Disaccommodated

A variety of USAF design and logistics problems are concerned with ascertaining the number of individuals who fall into a particular body size category. These problems fall into the realm of "tariffing," a term used by the clothing and personal equipment industry to mean a schedule showing

the relative numbers of each size of garment or other item that should be manufactured or purchased--of every 1,000 protective garments procured, how many should be short-regular? A closely related problem revolves around the concept of "proportions-disaccommodated"--how many USAF pilots would not be accommodated by a design specifying a maximum sitting height of 39 inches and a minimum thumb-tip reach of 29 inches?

USAF anthropologists have long followed the practice of providing tentative tariffs in technical reports describing the design of items of personal equipment. Whatever the USAF's future anthropometric program may be, it must retain the capability for creating tariffs for newly designed clothing and equipment.

Table IX shows a typical tariff and the basis on which it was constructed. Six boxes, corresponding to selected ranges of face and lip length were superimposed on the bivarate frequency table, and the numbers in each box were counted. When parts of a box of the original table fell within more than one size-box, the number of men within that box was divided among the appropriate sizes. The ultimate tariff for each size is the number associated with its size-box expressed as a percent or per mil of the total for all the size-boxes.

Tariffing from such data is not a precision operation. Some men are not fitted by their indicated size. Some are fitted by more than one size and may strongly prefer a size other than their indicated one. Many of the men who are not considered in establishing the tariff and fall outside all

TABLE IX

DESIGN RANGES AND TARIFFS FOR THE MC-1 ORAL-NASAL OXYGEN MASK

(from Anthropometric Sizing and Fit of the MC-1 Oral-Nasal Oxygen Mask by Emanuel et al., 1958)

Design Ranges and Tariffs

Size	Face Length	Lip Length	Tariff/1,000
Short-Narrow	3.90-4.40	1.70-2.10	186
Short-Wide	3.90-4.40	2.10-2.50	91
Regular-Narrow	4.40-4.90	1.70-2.10	368
Regular-Wide	4.40-4.90	2.10-2.50	163
Long-Narrow	4.90-5.40	1.70-2.10	142
Long-Wide	4.90-5.40	2.10-2.50	50

Face Length vs. Lip Length (Intervals in Inches)

FACE LENGTH

Lip Length	3.48-3.60	3.61-3.72	3.73-3.84	3.85-3.96	3.97-4.07	4.08-4.19	4.20-4.31	4.32-4.43	4.44-4.55	4.56-4.66	4.67-4.78	4.79-4.90	4.91-5.02	5.03-5.14	5.15-5.26	5.27-5.37	5.38-5.49	5.50-5.61	5.62-5.73	5.74-5.85	Totals
2.58-2.65								2	1												3
2.50-2.57								1			1	1		1	1						5
2.42-2.49					2	1	2	1	1				1								8
2.34-2.41					1	1	5	8	12	7	4	7	3	2	2	1					53
2.26-2.33					6	11	18	13	28	14	23	15	9	5	3	1	4				150
2.19-2.25				3	6	20	21	35	40	43	33	30	18	22	6	9	2	1		1	299
2.11-2.18	1		1	5	20	31	54	97	107	86	96	77	58	84	34	15	2	3	8		683
2.03-2.10			7	9	19	32	61	83	104	107	104	79	75	50	39	7	10	5	1		773
1.95-2.02	1		3	7	19	40	57	86	93	107	134	100	80	45	29	14	11	2	1		835
1.87-1.94			1	5	28	41	74	77	100	90	103	93	66	40	31	6	6	5	3		768
1.79-1.86		1	1	1	5	24	23	30	34	37	38	35	31	15	13	2	4	2			306
1.71-1.78			1	3	3	8	17	10	15	15	15	14	12	7	2	3	1	1			127
1.63-1.70			1		1	1	1	2		1	1	2	1	3	1	1	2				20
1.56-1.62								3	1	2	1		2		1						10
1.48-1.55											1				1						2
1.40-1.47																					
1.32-1.39							1														1
Totals	8	1	15	33	102	200	335	448	547	509	558	484	395	214	123	44	42	19	7	3	4095

the size-boxes will wear or use one of the sizes whether or not it fits. In addition to problems of this type and those related to manufacturers' deviations from design specifications, there are problems resulting from the practice of issuing an item during a particular time period to a limited subset of the USAF personnel. In practice, it is quite unlikely that we will know either the anthropometric nature of the subset or how to adjust a tariff to reflect anthropometric differences between this group of men and USAF personnel in general.

What the anthropologist can be expected to do is to provide a tariff of reasonable accuracy which will serve as a basis for initial procurements. More precise tariffs will be obtained only by adjusting these rough figures on the basis of actual field experience.

We do not believe additional large-scale surveys are necessary in order to continue providing tariffs similar to those we have provided in the past. We believe, in fact, that new approaches will make better information of this type more quickly available. Three points are relevant here.

First, tariffs depend solely on the distributions of the basic sizing dimensions. Thus, as long as the sizing dimensions for a new item are among those measured in the 1967 survey or are, in general, ones which can be computed from the measurements for these dimensions, we can create tariffs relative to the 1967 sample or an updated version thereof. This can be done whether a new design is based on data from the old sample or from a new, small-scale survey.

Secondly, a number of USAF sizing systems are based on height and weight. We presume there will be more, rather than less, height and weight data available in the future. If there are, it may be possible to examine the height-weight distributions for age-, task-, and command-specific subseries and perhaps provide better tariffs for items, such as arctic clothing, used only by certain segments of the USAF. It is also possible that the new data may be reported, rather than measured, heights and weights. One of the virtues of the height-weight sizing system has been that men presumably know their own heights and weights and consequently can determine their proper sizes. A strong case could therefore be made for basing sizing and tariffs on the reported rather than the measured values.

Thirdly, artificial bivariate frequency tables provide an approach which can be used even when actual "head-count" data are unavailable or do not exist, or when such data are too few in number to provide accurate results. These tables have the further advantage of making it easy to determine what effect a shift in either the basic design intervals or in the distributions of the basic dimensions in the proposed user groups has on a tariff.

We earlier asserted that the measured values of most body size dimensions follow a statistical pattern (specifically, that designated as approximately multivariate-normal) which permits us to compute any characteristic of the distribution of such variables from the basic statistics--means, standard deviations,

and correlation coefficients. We can, for example, compute from such statistics the proportion of a population which falls within a specific range or set of ranges.* When the ranges are based on two measurements, we refer to the outcome as an artificial bivariate table; the artificial bivariate approach to tariffing can be applied equally well to sizing systems based on one sizing dimension or on three.

Table X illustrates a group of tariffs for the six-size height-weight sizing system computed by this method and based on summary statistics from the 1950 and 1967 USAF surveys, the Turkish segment of the NATO survey, and on the heights and weights we have predicted for astronauts in the year 1985. For reasons already cited, we cannot be sure how accurate any of these figures are, but it is reasonable to suppose that the trends indicated by the statistics are fairly realistic. The tariffs for the two medium sizes (medium-short and medium-long) are essentially the same for all three U. S. populations, but there are drastic decreases in the smalls (38% in 1950 to 19% in 1985) and similar increases in the large sizes (9% in 1950 to 24% in 1985).

A major reason for conducting the NATO survey was that Turkish pilots were not adequately fitted by USAF partial pressure suits. Presumably, these suits were sent to Turkey on the basis of the USAF tariff; this table shows clearly why

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* While these computations are tedious, they are not complicated. They are performed quickly by a computer using a fairly simple program.

TABLE X

TARIFFS FOR SIX-SIZE HEIGHT-WEIGHT PROGRAMS
(Based on Artificial Bivariates)

A. Within Design Range:

	Small-Short	Small-Long
Turkish AF	41%	14%
1950 USAF	17%	21%
1967 USAF	10%	14%
1985 NASA	7%	12%

	Medium-Short	Medium-Long
Turkish AF	20%	5%
1950 USAF	21%	24%
1967 USAF	22%	29%
1985 NASA	20%	30%

	Large-Short	Large-Long
Turkish AF	1%	0%
1950 USAF	5%	4%
1967 USAF	9%	10%
1985 NASA	11%	13%

B. Outside Design Range:

	Too Small	Too Big	Too Short	Too Tall
Turkish AF	17%	0%	2%	0%
1950 USAF	6%	0%	1%	1%
1967 USAF	2%	2%	1%	2%
1985 NASA	1%	1%	1%	3%

the suits did not fit. On the basis of the USAF tariff, only one in every six suits should be a small-short, whereas the tariff based on Turkish Air Force heights and weights calls for 41% small-shorts and strongly suggests that an additional sub-small size, to be obtained by extrapolating the design values downward, be added to provide for the 17% of the Turks who were too small even for the small-short size.

A related problem is that of estimating the number of individuals who will not be accommodated by a design based on two or more variables. Rarely is it practical to design equipment or workspace to accommodate all potential users without adjustment. A typical solution is a design of the type suggested in the opening paragraph of this section (page 65)--one specifying cutoff values for a pair of dimensions. There, purely for purposes of illustration, we postulated a hypothetical set of cutoff values: a maximum 39-inch sitting height and a minimum 29-inch arm reach. Data from the 1967 survey indicate that 4.1% of the subjects exceeded the maximum sitting height and 4.6% had arm reaches below the indicated minimum. The total number not accommodated will not be the sum of these percentages (4.1 + 4.6) but rather this sum minus the number of men who both exceed the 39-inch value for sitting height <u>and</u> have an arm reach less than 29 inches; these men must be subtracted because they have been counted twice.

The initial values, 4.1% and 4.6%, were easily obtained from the frequency distributions or the percentile distributions. The third value (representing the number of men who

are out-sized in both dimensions) is not so easily come by since it depends on the correlation between sitting height and arm reach. However, a computer program similar to that used to prepare artificial bivariate tables and, like that one, based on the elementary summary statistics, can quickly compute this value.*

The use of computer programs to determine the number of men who will be disaccommodated by both of a pair of design limits can be extended to enable the design engineer to work out such problems as what pairs of values for sitting height and arm reach will leave 5% of the population disaccommodated, what pairs of values will leave 10% disaccommodated, and so on. Other questions of a similar nature which we have been called upon to answer range from the simple to the complex. How many USAF pilots are less than, 5'7" and 150 pounds? If eight-man groups are to be selected randomly from among USAF flying personnel who weigh less than 160 pounds, what is the probability that the eight men will collectively weigh no more than 1,200 pounds? Answers to these and many other such questions will be far easier to obtain from appropriate computer programs and the basic summary statistics than from a direct count of survey data.

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* Actually, in this example the third value will be quite small because men will rarely be too large in one long-bone measurement and too small in a second. The problem will be most serious when the two design values are closely related and the critical values are either both "large" or both "small" ones.

Long Term Trends in Size and Shape

Men, both individually and collectively, change in body size and shape with the passage of time. The importance to the USAF of having some sense of the directions and magnitudes of these changes has been discussed earlier. Unfortunately, these trends are not easily measured and it has, in fact, been argued that trends as such do not exist. Undoubtedly the differing sizes of USAF bodies at different times can be attributed to a variety of factors among which long term trends may not be the most important.

One recent attempt to isolate and evaluate such trends was carried out by the AMRL in response to a request from NASA to predict the body size of astronauts in 1985. The initial assumption of this study was that it could best be done by predicting the size of USAF pilots who will be in their mid-thirties in 1985 and accepting these predictions as being suitable for astronauts as well.

We began our study by analyzing the available data for stature. This is not only the most important dimension but probably the easiest one to study. We can assume that an aviator's stature remains fairly constant from the time he reaches full growth--at 23 years or younger--until, in general, the end of his active flying career. Assuming a simple long term trend, stature for men in this age range would be a function of year of birth. To study this trend we used data from the 1950 flying personnel survey for birth years 1915-1927; from the 1957 PhotoMetriC survey for the years 1922-1934; from

the Navy flying personnel survey for the years 1929-1941; from the 1965 USAF survey for the years 1930-1942; and from the 1967 flying personnel survey for the years 1932-1944. In 1973 we conducted a brief survey of about 500 student pilots and navigators, aged 23 to 27, to obtain coverage of the years 1946-1950. The 23- and 24-year-old men measured in the latter survey were particularly important for this study since they will be in their mid-thirties in 1985.

In analyzing these data, an effort was made to minimize background variables by eliminating all non-officers from the data. Non-Caucasian subjects, however, were not eliminated because they were too few in number to have any real effect.

Some of the data from this analysis appears in Table XI. These data indicate that an upward linear trend of sorts does seem to occur at the rate of about eight millimeters a decade. But other questions arise. Why, for example, is there no clear-cut trend for the subjects in any single survey group? A comparison of the statures of youngest and oldest men considered in each survey gives the following erratic results:

	OLDEST			YOUNGEST			
Survey	Birth Year	Age	Stature	Birth Year	Age	Stature	Difference
1950 USAF	1915	35	175.88	1927	23	176.18	= 0.30 cm
1957 USAF	1922	35	176.67	1934	23	176.75	= 0.08 cm
1964 Navy	1929-32	33	177.72	1939-41	24	177.73	= 0.01 cm
1965 USAF	1930-31	35	177.26	1941-42	24	176.44	=-0.82 cm
1967 USAF	1932	35	177.76	1944	23	177.41	=-0.25 cm
1973 USAF	1946	27	178.13	1950	23	178.49	= 0.36 cm

It is difficult in light of data such as these to accept the idea that changes in stature are solely, or even predominantly,

TABLE XI

MEAN STATURES FOR USAF AND NAVY OFFICERS BY YEAR OF BIRTH

Birth Year	USAF 1950		USAF 1957		NAVY 1964		USAF 1965		USAF 1967		USAF 1973	
	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N	$\bar{X}$	N
1915	175.88	54										
1916	174.56	128										
1917	175.25	136										
1918	176.24	154										
1919	175.72	164										
1920	176.34	209										
1921	175.81	260										
1922	176.03	267	176.67	98								
1923	176.42	242	176.13	75								
1924	175.80	288	176.50	70								
1925	175.57	258	176.26	57								
1926	175.88	200	177.75	26								
1927	176.18	209	177.43	29								
1928			175.13	36								
1929			177.22	58	177.72	59*						
1930			175.90	52	177.72	59	177.76	30				
1931			177.22	77	177.72	59	176.82	39				
1932			176.81	147	177.72	59	176.67	43	177.76	104		
1933			177.32	173	176.85	85	177.65	44	177.56	111		
1934			176.75	133	176.85	85	175.98	39	176.74	111		
1935					176.85	85	176.81	27	177.20	103		
1936					177.55	128	178.28	31	177.32	91		
1937					177.55	128	177.73	26	176.68	75		
1938					177.55	128	177.22	21	176.81	96		
1939					177.73	141	181.16	15	177.30	114		
1940					177.73	141	178.81	30	178.19	145		
1941					177.73	141	177.66	23	176.56	156		
1942							176.19	29	177.47	168		
1943									177.75	247		
1944									177.41	260		
1945												
1946											178.13	54
1947											177.15	75
1948											178.43	122
1949											178.01	123
1950											178.49	93

* Original data grouped in 3 or 4 year intervals.

the result of a broad regular genetically-related pattern of growth, on the basis of which we can predict with confidence stature values for the future.

Other dimensions present additional problems. Fleshy measurements, including weight, cannot be assumed to be independent of age, and the problem of trying to establish trends for them becomes complicated by the need to consider both age and year of birth. In any one survey, these two variables are inflexibly tied together. The tendency of large surveys to have similar average ages presents further obstacles to separating age and year of birth.

In this study a working assumption was made that the ponderal index (height divided by the cube root of weight) was independent of year of birth. With this assumption it was possible to make weight predictions although inconsistencies in the original data certainly made the soundness of the entire exercise questionable. Attempts to establish extrapolative trends for circumferences and similar measurements seemed even less feasible; 1985 values for these measurements were estimated using regression equations and predicted heights and weights.

The evaluation of secular trends for many dimensions and shape indices are further complicated by difficulties in obtaining precise, accurate measurement. Two illustrations of the problems which arise will suffice.

A pair of indices of importance in applied anthropometry is sitting height divided by stature and crotch height divided by stature. These indices are more or less complementary; they add

up to almost exactly 100%, and as a rule one decreases when the other increases. Which one increased from 1950 to 1967? The answer, puzzlingly enough, is that both increased by almost equal amounts. In 1950, sitting height was 52.0% of stature; in 1967 it was 52.5%. In 1950, crotch height was 47.5% of stature; in 1967 it rose to 48.0%. Detailed analyses of the data confirm these discrepancies and efforts to explain them in terms of differences in weight and age of the two samples have been fruitless. The simplest and most likely explanation is, alas, that one or both of these dimensions were measured differently in the two surveys.*

The most classic of the body shape indices is probably the cephalic index, head breadth divided by head length.** For the 1950 survey, this index was 78.2%; for the 1967 survey it was 78.5%, a statistically significant difference. However, since the difference could result from a shift of less than 0.7 millimeters in head breadth and no effort was made in either survey to measure head lengths and breadths more closely than to the nearest millimeter, this "statistically significant" difference could well reflect nothing more than variations in measuring procedures.

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* These indices are racially related; Blacks have smaller sitting height indices than Whites, Whites smaller ones than Orientals. Similarly the crotch height index tends to be smallest for Orientals and largest for Blacks. Analyses of these indices for groups containing substantial numbers of Blacks or Orientals should be done on racially-specific subseries.

** The comments of the previous footnote also apply to cephalic index. The order of relative size is the same as that for the sitting height index.

Most of the data in these attempts at trend analysis were obtained from large surveys. The problems sketched here and others encountered in the use of these data for studying trends point up the fact that such surveys do not provide the data needed for serious trend analysis. We do not pretend to know just how surveys should be conducted or how samples should be selected to obtain adequate data for such analysis--or even if it can be done.

One simple strategy, however, is available. In estimating astronaut statures for the 1980's, it was assumed that our concern was with men who would be in their early and mid-thirties at that time. In a sense, it was not necessary to estimate these men's statures: we could go out and measure them. Men with appropriate birth years were then (1973) already participating in USAF pilot and navigator training programs. A survey was, therefore, carried out at two training bases. Statures and other data were quickly obtained for about 500 men, 23 to 27 years old, men, that is, with full growth who will be from 30 to 34 in 1980 and from 35 to 39 in 1985.

A similar procedure can be used to provide data for the USAF itself. USAF flying crews, judging on the basis of the 1950 and 1967 surveys, average somewhere around 30 years of age. It is reasonable to assume that at any given time the USAF flying personnel who, as a group, are of average age will also be of average stature. Hence, we can determine the average stature of these men seven years in advance simply by measuring the 23-year-olds as they go through USAF pilot and navigator

training programs. Adequate data for providing a seven-year lead time can thus be obtained by a two-man measuring team in a single week and tabulated and summarized in a similar time period.

We know of no equally simple and potentially reliable basis for providing a similar lead time for weight. Accurate estimates of stature would, however, seem to be at least a prerequisite and a useful first step to obtaining proper estimates of weight.

Data Relating Body Size to Low Probability Incidents

Pilots occasionally eject in flight with tragic results, while other pilots eject without trauma. It is reasonable to suppose that there are anthropometric factors contributing to the outcome of such ejections, and that it would be useful to compare the body dimensions of pilots who eject successfully and those who eject unsuccessfully. Data for men in the former group can, in theory at least, be obtained after the fact, but this is not possible for the latter group. Fortunately, the number of men in the second group--even over a period of years--is rather small, and very few men who will later fail to survive ejection are likely to be included in surveys with sample sizes of 2500-4000. In short, data, beyond some height and weight figures from medical records, do not generally exist for studying the size and shape factors which differentiate the successful from the unsuccessful ejectors.

The official end of USAF activities in Vietnam was followed by the return of a number of USAF fliers from POW camps. AMRL was asked at that point to provide whatever anthropometric data existed for these men so that changes in their dimensions as a consequence of their POW experiences could be assessed. Despite the fact that many of the subjects of the 1967 survey were on their way to Vietnam at the time they were measured, only a meager handful of the POW returnees were found to have been included in the 1967 sample.

The problem of providing data on POW returnees and on men who have undergone seat ejection are but two examples which point up the USAF need for data which must be obtained on men in advance of any knowledge of their involvement in low-probability incidents. Because the number of such men is small, data for them are not likely to be available unless data are available for an exceedingly large proportion of the USAF population.

We believe that the best prospect for providing the needed data is a survey which can create a large reservoir of "latent data" at a low time-and-effort cost per man. Our recommendation is the creation of a "library" of standardized photographs which, within a period of a few years, would include most USAF flying personnel. Then, whenever the need arises for a man's data, it would be possible to extract his photograph and convert the "latent data" contained in it to workable information ready for analysis.

Research on the feasibility and potential usefulness of a photographic project to serve this and a variety of other purposes is currently underway.

Data Related to Racial and Other Group Differences

The relatively small number of non-Caucasians among USAF flying personnel and, as far as we know, among upper level NCO's and non-flying officers, makes the problem of acquiring anthropometric data for these men somewhat difficult. Extreme care is required to insure that differences in measuring techniques will not blur existing body size differences or create differences where they do not exist. Several recent articles in the American Journal of Physical Anthropology demonstrated apparently vast anthropometric differences between groups of data, in cases where measurements were made on the same people by different anthropologists. Fortunately, the USAF's need for data in this area is a limited and practical one. The basic question is not really whether Black pilots have, say, larger or smaller waists than do White pilots, but whether anti-g suits based on data from White pilots will fit Black pilots, although, of course, the answer to the first question can be of value in anticipating the answer to the second. Fortunately, too, U. S. Whites are a very heterogeneous group. In a study of Black and White basic trainees we made some years ago, almost all Blacks fell within the White range on almost all measurements except those of the face. It is in the area of facial measurements that the greatest need exists for

race-specific data. This need cannot be adequately met by extracting data from a large-scale general-purpose survey. It will require a study carefully designed and executed for the specific purpose.

The major group differences with which USAF designers must cope are, of course, those between men and women. To a large extent, the data documenting these differences already exist.

CHAPTER VII

MEASUREMENT AND SAMPLING ERRORS AND A DEFINITION OF ACCURACY

An essential element in the design of an anthropometric survey is some basis for judging how large a sample will be required to provide "adequate accuracy." In this chapter we will propose an objective definition of adequate accuracy for data to be used for design purposes and in the next chapter we will discuss the size of samples which would be required to satisfy this definition for most common anthropometric dimensions.

First, however, it is useful to consider the nature of the errors which affect anthropometric data and to explore how the errors in the individual data affect the accuracy of the usual statistical summaries. In particular, it is useful to note which error effects are related to sample size and which ones, being independent, cannot be reduced by increasing the sample size.

Ideally, a sampling procedure should be designed to give an appropriate level of accuracy--and no more. Accuracy beyond a useful level is not only expensive to obtain and wasteful but may well be illusory as well. Often an increase in one aspect of overall accuracy will be achieved at the cost of decreases in other aspects of accuracy. A decrease in random sampling error obtained by a large increase in sample size, for example, may be negated by increases in measurement

error resulting from a concomitant reduction in the time available for the careful posing of subjects and taking of measurements.

The Relationships Between Measurement Errors and Accuracy

Anthropometric data, like data from other fields of measurement, are, of course, subject to error; both the individual measurements and the statistical summaries based on these measurements will, in varying ways and to varying degrees, be in error. Among the factors which contribute to these errors are the following:

1. inaccurate measuring
2. inaccurate posing or positioning of subjects
3. inaccurate measuring equipment
4. uncontrolled variation in the subjects
5. sampling errors

Some of these factors represent errors in a real sense; that is, they reflect flaws in the design and execution of the total data gathering process which affect the accuracy of both the individual data and the statistical summaries. Theoretically, though not practically, these flaws could be eliminated or reduced to trivial levels, even for small samples.

In addition, the accuracy of most of the statistical summaries is affected by random (and perhaps non-random) sampling errors which do not represent flaws in the data gathering as much as they reflect the inherent variability of the dimensions being measured. The size of these random errors depends, among

other things, on the standard deviation of these dimensions and their overall magnitude can be estimated from the data themselves. As we shall see, the size of these errors can be reduced both by increases in the sample size and by the use of matched or controlled sampling.

It may be of value to consider the way errors in the individual data affect statistical summaries such as the mean, standard deviation, percentiles, design ranges, and correlation coefficients. We will deal with this here in a more or less exploratory, rather than a mathematically rigid, form. We begin with the assumption that each source of error has both a constant sytematic element, μ_i, and a random element which has a mean of zero and a standard deviation of σ_i.* Thus, for example, a scale might give weights which on the average are μ pounds too high, and such that the error in the individual weights fluctuates up and down from this average by amounts proportional to some value σ.

Where, as is usual, there are several sources of error, the systematic and random elements combine to determine the overall errors of the data. The two types of errors combine rather differently. The systematic element of the total error (μ_T) is simply the sum of the individual systematic errors:

$$\mu_T = \Sigma \mu_i$$

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* The various error elements affecting a particular set of data are assumed to be, in a statistical sense, unrelated.

The random element of the total error obtained will have a standard deviation (σ_T) obtained by adding the squares of the individual random errors and taking the square root of the sum:

$$\sigma_T = \sqrt{\Sigma\sigma_i^2}$$

Since $\Sigma\mu_i$ represents an algebraic sum it is possible for some systematic errors to be balanced off by others. Every random error, on the other hand, tends to increase the size of the overall random error, although σ_T is often only slightly larger than the largest of the σ_i.

These two types of error factors in the data affect the accuracy of the statistical summaries in rather different ways.

The Mean. The error components of the mean value as calculated from a sample of size N will be:

$$\Sigma\mu_i \text{ and } \sqrt{[(SD)^2+\Sigma\sigma_i^2]/N}$$

where SD represents the actual (not the observed) standard deviation.

The random factor, essentially what is often referred to as the standard error of the mean, decreases in size with increasing sample size. However, an increase in sample size does not cause a proportionate decrease in this error. To cut this error in half will require quadrupling the sample size; to reduce it to one-third will require a sample nine times as large, and so forth. Equally important, if not

more so, is the fact that the size of the systematic error is in no way affected by the sample size.

The Standard Deviation. The errors of the standard deviation are somewhat different. The two components are

$$\sqrt{(SD)^2+\Sigma\sigma_i^2} - SD \quad \text{and} \quad \sqrt{[(SD)^2+\Sigma\sigma_i^2]/2N}$$

Unlike the sample mean, the sample standard deviation (a) is unaffected by the systematic errors in the data and (b) has a systematic error element which is due to random errors in the data.

The systematic component of the error of the standard deviation is always positive, resulting in a consistently positive bias in the sample standard deviation. The random component is similar to that of the mean, being equal, in fact, to the standard error of the mean divided by the square root of two. The random component thus can be reduced by increasing the sample size, but no such reduction can be made in the systematic error.

The Percentiles. The errors associated with percentiles are a bit more complex and are related to the method by which they are computed. Percentile values for use in solving design problems are often approximated as values located a certain number of standard deviations above or below the mean, e.g., $\bar{x}$ - 1.63 SD for the 5th percentile, $\bar{x}$ + 1.63 SD for the 95th percentile, and so forth. We shall base our discussion of percentiles on approximations of this type. Because the sample means and sample standard deviations from normal

distributions are statistically independent, the errors of these approximations are simple combinations of the errors of the mean and the standard deviation. Designating the approximations as $\bar{x} + K \cdot SD$, the two error components are:

(a) Syserror $(\bar{x} + K \cdot SD)$

$= \text{SYSERROR}(\bar{x}) + K \cdot \text{SYSERROR}(SD)$

(b) Ranerror $(\bar{x} + K \cdot SD)$

$= \sqrt{[\text{Ranerror}(\bar{x})]^2 + K^2[\text{Ranerror}(SD)]^2}$

As is the case with the mean and standard deviation, these error components have elements which are dependent and elements which are independent of sample size. As is the case with the sample means, these percentile estimates may be either too large or too small. But since errors in the data tend to increase the size of the standard deviation, a design range based on a complementary pair of percentiles--say, the 5th and the 95th--will always tend to be excessively wide as a result of the errors in the original data. The systematic error in the width of the design range, based on approximations to the 5th and 95th percentiles, will be about 3.29 times the systematic error of the standard deviation.

<u>The Correlation Coefficient</u>. After the mean, the standard deviation and the percentiles, the correlation coefficient is the most important summary statistic for most design purposes. The effects of measurement and sampling errors on the correlation coefficient are somewhat more complex than those for the statistics already discussed, and we will limit ourselves to

a consideration of the effect of measurement errors for samples large enough as to render sampling errors unimportant. If, in this case, the measurement errors of variables x and y are independent of each other, the observed correlation $R^*(x,y)$ will be related, on the average, to the true value $R(x,y)$ by the formula:

$$R^*(x,y) = \frac{R(x,y)}{\sqrt{\left(1 + \frac{\Sigma(\sigma_{i,x})^2}{SD_x^2}\right)\left(1 + \frac{\Sigma(\sigma_{i,y})^2}{SD_y^2}\right)}}$$

The random measurement errors will in all cases increase the denominator of this expression and consistently depress the size of the observed correlation coefficients.

It is not practical to consider here the case in which measurement errors for x and y are not independent; in practice the existence of relationships among the errors for two measurements will occur and may substantially affect the correlation coefficients. Related errors would occur, for example, when two measurements such as sitting height and eye height, sitting, are measured without a change in the subject's position. If a subject sits overly erect both measurements may be too high, while both values for a semi-slumped subject will be too low. Such errors may lead to exceedingly exaggerated correlation coefficients. In general, however, measurement errors tend to deflate the correlation coefficients. Atypically small correlation coefficients, in fact, at times provide a basis for suspecting the existence of serious measurement errors.

Thus, both the random and the systematic or non-random components of the measurement errors adversely affect the mean, the standard deviation, the correlation coefficient, the percentiles and the width of design ranges based on the percentiles. Not only do the systematic errors of the measurement data enter into the errors of these statistics without regard to sample size, but the random errors can also affect the accuracy of the statistics in a manner which is independent of sample size. In no case can the effect of measurement error be eliminated by increases, even drastic ones, in the sample size.

It would be incorrect, however, to assume that reasonably accurate statistics cannot be obtained without unrealistically precise data. The non-random components of the measurement errors do add together directly but careful planning and execution of a survey can keep their total small. The effect of random error components will be quite small as long as they are of modest size compared to the standard deviation. Thus, for example, if statures are measured with a random error of one centimeter, the bias in the resulting standard deviation estimate, assuming a true standard deviation of six centimeters, can be estimated from the formula

$$\sqrt{(SD)^2 + \sigma^2} - SD = \sqrt{6^2 + 1^2} - 6 = 0.08 \text{ cm.}$$

In this case the random measurement error of one centimeter has caused a bias of less than a millimeter or about 1% of the standard deviation. Generally, the effect of random error components on the standard deviations do tend to be modest in

anthropometric measures of large size, but often become relatively meaningful when the dimension being measured is small like ankle height.

Appropriate Levels of Accuracy

It is impossible, as a rule, to specify in advance how accurately any body size parameter needs to be known and to design a survey which would provide such accuracy. Accuracy must be specified in terms of a particular design-manufacturer-use context and requires the analysis of a multiplicity of factors many of which, like the required accuracy, are unknown in the abstract.

Nonetheless, we believe that some basis for a rational approach to the concept of adequate accuracy can be developed and from this approach we can develop some sense of the sample size necessary to keep random sampling errors within appropriate limits. In developing our approach to this problem we make some assumptions unsupported by hard facts and, at times, we indulge in fuzzy reasoning. However, we feel that our results make sense and, in the absence of a better approach, can be used profitably in designing a survey.* The discussion here will assume random sampling and the results of the discussion will subsequently be extended to matched samples.

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* We could, it is true, formulate a "cost-function" (in the sense of Wald) involving the ultimate costs of erroneous data plus the costs of obtaining the data. By setting the derivative of this function with respect to N equal to zero and solving for N, we find the value of N which minimizes the total cost. However, the information necessary to convert this from a theoretical approach to a practical one does not exist.

We base our approach on the assumption that it is sufficient to know design values within either of the following limits: (1) the daily variation of the potential users' anthropometric measures or (2) the preciseness with which a manufacturer will follow a design.

A man's body constantly varies in size, not just over lengthy periods of time but over quite short periods as well. His chest circumference, for example, varies plus or minus one percent or more from its mean value every six seconds or so with breathing. A man's stature decreases from the time he leaves his overnight horizontal position until he returns to it. Olivier (1969) suggests that this decrease is about 20 millimeters and Damon (1964) quotes an early study by Backman which postulates a value of 0.95 in. (24 mm). Both these values can be interpreted as essentially equal to one percent of mean stature.

Items of clothing, protective equipment, and workspace to be anthropometrically suitable for any individual must be suitable for him throughout his working day. It would seem, therefore, that any design which requires design values more precise than the variation which occurs in a human being within a normal day is, ordinarily at least, unrealistic.

Thus, we suggest that for estimating stature, a sample will be of acceptable size if it is so large that random sampling error will be, in general, less than one percent

of mean stature.* The argument for accepting one percent of the mean value as the criterion for the accuracy required for other measurement data is, perhaps, less direct.** Nonetheless, it seems a reasonable criterion and one which we have accepted.

The random sampling error for many small dimensions is compounded by a relatively large measurement error. For such dimensions rather large samples would be required to provide a precision of one percent of the mean value. The one percent criterion may also be unrealistically low for these dimensions because of the small mean values. We have, therefore, accepted as the basis for a second criterion the notion that precision beyond that with which a manufacturer will follow a design is unnecessary.

What precision a manufacturer will follow in the design and fabrication of an item in the future we do not know, of course. It is relevant to note, however, that for many USAF designs created over the past two decades, the anthropometric data have been reported in quarter-inch units because USAF anthropologists working closely with the manufacturer have insisted that the manufacturers would not use more

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* We are more or less equating a mean change of 1% with a random error of 1%. This is an example of the fuzzy thinking which we have already admitted to; data on diurnal patterns of variation are too sketchy to enable us to properly assess the reliability of our assumption.

** We shall relax this criterion slightly in the next chapter to 1.5% for fleshy measurements, based on the magnitude of breath-to-breath variation in chest circumference.

detailed data. For some items, particularly those such as helmets and masks which relate to the head and face, the reporting unit has usually been one-tenth of an inch. Whichever of these units is used in reporting the data, it is reasonable to assume that a precision equal to or less than the reporting unit will be satisfactory.

It seems reasonable, therefore, to expand our definition of acceptable sample size to include those which provide a precision of either (1) one percent of the mean value or (2) the smaller of the units in which the data are normally provided by the manufacturer--that is, one-tenth of an inch. In general, the minimum sample size for large dimensions will be determined by the first and that for small dimensions by the second of these criteria.

We have used the terms accuracy and precision in this chapter without clearly defining them. Our discussion of the errors of the more important summary statistics demonstrated that each of these statistics has different error components and that definitions of accuracy differ accordingly.

When anthropometry is applied to design problems, considerable use is made of the approximations to the 5th and 95th percentiles obtained by subtracting or adding 1.65 standard deviations to the mean value. Because of the extensive applicability of this use and the fact that these percentile estimates have substantially higher sampling errors than do the mean and the standard deviation, we have based our definition of accuracy on the 5th and 95th percentiles.

Because the mean and the standard deviation are independent of each other in the normal distributions, the random sampling error of the quantity (the mean plus a multiple of the standard deviation) is given by the formula:

Sampling error ($\bar{X}$ + K·SD)

$$= \sqrt{[\text{Sampling Error } (\bar{x})]^2 + K^2\,[\text{Sampling Error (SD)}]^2}$$

$$= \sqrt{\frac{(SD)^2}{N} + K^2\,\frac{(SD)^2}{2N}} \qquad = \frac{SD}{\sqrt{N}}\sqrt{1 + \frac{K^2}{2}}$$

Setting K = 1.65, we get

Sampling error (estimated 5th or 95th percentile)

$$= \frac{SD}{\sqrt{N}}\sqrt{1 + \frac{(1.65)^2}{2}} = 1.53\,\frac{SD}{\sqrt{N}}$$

The criterion of adequate (random sampling) accuracy which we have chosen is--for reasons given below--that twice this quantity be less than 1% of the mean or 0.1 inch, whichever is larger:

$$\frac{3.06\ SD}{\sqrt{N}} < 0.01\ \bar{x} \quad \text{or} \quad \frac{3.06}{\sqrt{N}} < 0.1 \text{ inch.}$$

Equivalently, we define as an acceptable sample size (relative to a specific variable) one such that:

$$N > \left(\frac{3.06\ SD}{0.01\bar{x}}\right)^2 \quad \text{or} \quad N > \left(\frac{3.06\ SD}{0.1}\right)^2$$

We chose twice the sampling error because by the laws of probability we can expect the random sampling error of these

percentile estimates, based on such samples, to be less than 1% $\bar{x}$ or 0.1 inch, whichever is appropriate, 95 times out of 100.*

Because the percentile estimates have larger random sampling errors than the mean and the standard deviation, the latter parameters will be estimated with smaller sampling error. When the random sampling for the percentiles is 1% of the mean, that for the mean will be about two-thirds as large (0.65% $\bar{x}$) and that for the standard deviation less than half as large (0.46% $\bar{x}$).

A useful variant of this statement is that when the odds are 95 out of 100 that the random sampling errors of the percentile estimates are no more than 1% $\bar{x}$, the corresponding odds are 998 out of 1,000 for the sample mean and 99,997 out of 100,000 for the sample standard deviation.

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* A more stringent definition of precision can be based on using 3 SE, i.e., 4.59 SD/$\sqrt{N}$. The odds in this case would rise to 997 out of 1,000. This definition of precision would require samples 2.25 times as large as those based on the 2 SE definition.

CHAPTER VIII

SMALL MICROCOSM SAMPLES--MATCHED AND UNMATCHED

The discussion of errors and the definition of adequate accuracy presented in the preceding chapter lead naturally to the question of how large microcosm samples need to be in order to provide minimum sampling accuracy for typical body size dimensions. We shall explore the answer to this question here and shall demonstrate that samples of a few hundred subjects can often be adequate.

The definition of adequate accuracy suggested in the previous section--that is, that the standard error of the estimated 5th and 95th percentiles be less than either 0.5% of the mean value or 0.05 inches--provides a relationship between the variability of the data and the size of the sample necessary to satisfy these criteria. The requirement that the standard error be less than 0.5% of the mean value will be satisfied whenever the sample size (N) and the coefficient of variation (V) are related by the expression:

$$V < 0.0326 \times \sqrt{N} \ \%$$

Similarly the requirement that the standard error be less than 0.05 inches can be expressed in terms of the sample size and the standard deviation (SD) by the expression:

$$SD < 0.0326 \times \sqrt{N} \text{ inches}$$

Table XII provides the maximum values of V and SD which satisfy these relationships for a number of values of N. The first line in this table, for example, indicates that for samples of 100, any variable with a coefficient of variation not exceeding 3.26% will have a standard error for the percentile estimates of 0.5% of the mean or less, and any variable with a standard deviations of 0.33 inches will have a standard error of no more than 0.05 inches. Note that a random sample of 400 men is nee^d^ed to provide similar accuracy for measurements of twice as great variability (V <6.52%, SD <0.65 inches).

TABLE XII

RELATIONSHIP BETWEEN COEFFICIENT OF VARIATION, STANDARD DEVIATION (SD), AND SUGGESTED ACCEPTABLE SAMPLE SIZE (N)

N	V (%)	SD (in.)
100	3.26	.33
150	3.99	.40
200	4.61	.46
250	5.15	.52
300	5.65	.57
350	6.10	.61
400	6.52	.65
450	6.91	.69
500	7.29	.73

This table provides a basis for estimating the appropriate sample size for a contemplated survey. Prior to the conduct of a survey, means and standard deviations of the dimensions to be measured will not be known precisely. Usually, however, these statistics can be approximated closely enough to make sensible use of this table. Rough approximations of mean values can, as a rule, be easily obtained. The fact that the

coefficients of variations are relatively equal for anatomically similar dimensions usually provides a basis for estimating the coefficient of variation which, along with the approximation to the mean value, can also provide a useful estimate of the standard deviation.

Since the sample size requirements are tied to the coefficients of variation and standard deviations, it will be worthwhile to consider the distribution of coefficients of variation and standard deviations for the measurements made in the 1967 flying personnel survey and the WAF survey. These distributions are given in Table XIII.

Consolidating values from the last two tables, we get the following proportions of the measurements made in these surveys that could have been "adequately" measured according to our criterion with samples of various sizes:

Sample Size	Proportion of Variables for Which Sample would be Adequate: 1967 Survey Data	Proportion of Variables for Which Sample would be Adequate: WAF Survey Data
100	28%	22%
150	39%	34%
200	51%	52%
250	70%	60%
300	79%	67%
350	84%	75%
400	87%	80%
450	89%	86%
500	91%	89%

Data for 9% of the variables in the flying personnel survey and 11% of those in the WAF survey would not satisfy our criterion of adequate accuracy even on samples of 500.

Thus, about 70% of the 185 linear measurements made in 1967 could have, in the sense we have developed here, been

reliably measured on a sample of 250; 79% on a sample 300; 84% on a sample of 350; 91% on a sample of 500. A sample of about 1,000 would have been required to include all the variables.

TABLE XIII

DISTRIBUTIONS OF STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION FOR VARIABLES MEASURED* IN ANTHROPOMETRIC SURVEYS OF USAF FLYING PERSONNEL (FP) AND WOMEN OF THE AIR FORCE (WAF)

Standard Deviations (inches)	FP	WAF	Coefficients of Variation (%)	FP	WAF
2.4 & up	7	5	10.0 & up	17	10
2.2 - 2.4	4	5	9.5 - 9.9	2	2
2.0 - 2.2	3	6	9.0 - 9.4	0	4
1.8 - 2.0	3	3	8.5 - 8.9	4	8
1.6 - 1.8	11	5	8.0 - 8.4	7	4
1.4 - 1.6	11	4	7.5 - 7.9	12	4
1.2 - 1.4	7	6	7.0 - 7.4	9	5
1.0 - 1.2	17	4	6.5 - 6.9	6	8
0.8 - 1.0	22	18	6.0 - 6.4	11	14
0.6 - 0.8	15	16	5.5 - 5.9	12	17
0.4 - 0.6	27	16	5.0 - 5.4	32	14
0.2 - 0.4	34	22	4.5 - 4.9	35	13
0.0 - 0.2	24	12	4.0 - 4.7	16	12
			3.5 - 3.9	14	6
			3.0 - 3.4	7	1
			2.4 - 2.9	1	--

* Excluding weight and grip strength and, for the WAF's, the over-foundation-garment measurements.

It may be worth noting for which measurements the sample size criteria would not have been met with an N of 350. They are:

10 <u>fleshy circumferences</u> (chest, waist, waist/sitting, buttock/sitting, upper thigh, upper thigh/sitting, biceps relaxed, biceps/relaxed-left, biceps/flexed, biceps/flexed-left);

7 <u>fleshy breadths and depths</u> (chest, waist, bicristale, and forearm-forearm breadths; chest, waist, buttock depths);

11 <u>surface measures</u> not related to a pair of bony landmarks (six scrotale-to-waist measures, spine to scye length, crotch length, interscye, anterior and posterior neck lengths);

3 <u>miscellaneous</u> (elbow-rest height, calf height, weight).

This list can be summarized as consisting of 28 fleshy measurements and three miscellaneous measurements which constitute an unclassifiable group. Elbow-rest height is an example of those measurements which do not represent an actual body dimension, but rather a difference between two dimensions (shoulder height, sitting and shoulder-elbow length). Such measurements will always have high coefficients of variation, ranging up to almost infinite values when the mean values of the two dimensions are approximately equal.

The presence of calf height on this list illustrates the point that even a height measure acquires a level of fuzziness when its landmark is not a well defined bony point.

Weight is, of course, a rather special dimension. Whereas all the other dimensions are linear in nature, weight is a cubic quantity. It could be argued, therefore, that for purposes of this analysis, we should consider not weight but its cube root, $\sqrt[3]{Wgt}$. If we do that, we get a measurement with a coefficient of variation close to one-third* of that for weight. Since the coefficient of variation for weight was about 12%, we would expect the coefficient for its cube root to be about 4%, suggesting that this variable could be adequately measured on a fairly small sample.

We propose, on the basis of this analysis, to modify our definition of precision by increasing the acceptable error in the circumferences, breadths and depths of fleshy measurements and in surface measurements without two bony landmarks--from 1% of the mean or 0.1 inch, to 1.5% of the mean or 0.15 inch. These values are well within the cyclic variation of chest circumference and probably well within the differences that result from different levels of tension on the measuring tapes or compression of the calipers. This change has the effect of multiplying, for measurements of

* The value of V for $\sqrt[k]{X}$ is approximately 1/k that for X, the value for X^k is approximately k times that for X.

this type, the values of V and SD in Table XII by 1.5 for all values of N (i.e., samples of 100 will be adequate for V <4.89% and SD <0.5 inches).

With this modified definition of precision, a sample of 350 men would have been adequate for all the linear measurements made in the 1967 survey with three exceptions--elbow-rest height, calf height, and interscye. Reasons for the highly variable nature of the first two have been commented upon. As for the interscye, rather than casting about for explanations, we bluntly express our conviction that interscye was not properly measured in this survey.*

Although a large number of measurements were made in 1967, clearly there are others which might have been made. The 1950 USAF survey, the NATO survey, the U. S. Army Aviators survey, and the recent RAF survey between them included some 50 additional measurements. Every one of these could also have been obtained from a similar sample of 350 men. Thus, all but two or three out of nearly 240 dimensions could have been measured reliably on samples of 350 men.

Analysis of the data from the WAF survey provides similar results. Using our initial criterion of 1% of the

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* Interscye has long enjoyed a reputation as an unreliable measurement, with a range of definitions and mean values which vary from survey to survey. The coefficients of variation, however, have been fairly consistent: 1950 Flying Personnel, 7.1%; NATO, 7.7%; Army Aviators, 7.5%; 1965 USAF, 7.9%; WAF, 7.0%. Why 9.8% for this survey? We don't know.

mean or 0.1 inch, some 31 measurements would have required samples of more than 350. Of these, 16 are circumferences, 8 breadths or depths, 4 surface measurements and 3 miscellaneous: weight, elbow-rest height and waist height/sitting. On the basis of the relaxed criterion of 1.5% of the mean or 0.15 inch, only two of the linear measurements--elbow-rest height and biceps circumference/relaxed, left--would have required a sample in excess of 350.

The possibility of increasing the precision of sample results by using matched or adjusted sampling has been mentioned. At this point, we will consider the improvement which we could expect if a microcosm sample were selected to agree with the population it is intended to resemble in terms of the standard summary statistics for selected basic measurements. Height and weight--as matching variables--could be expected to provide the greatest improvement. However, since it seemed likely that reported heights and weights were more likely to be available than the corresponding measured values, this analysis was begun by comparing the multiple correlation coefficients for all other variables based on the heights and weights as reported by the subjects with the correlation coefficients based on measured heights and weights. The agreement is high, as reported earlier, with a median difference of only 0.02, indicating that the reported heights and weights would serve almost as well as the measured heights and weights in matching sample to population.

Regression equations for the 1967 survey based on measured heights and weights and those based on reported heights and weights appear in Appendix 2 (A and B). Similar equations for the WAF's based on measured data appear in the report of that survey. If these equations are to be used, the standard error of estimate will replace the standard deviation in our analyses.

The following values show how well matching reported heights and weights to population values would do (1967 survey data):

Sample Size	Proportion of Variables* "Accurately Estimated"
100	55%
150	79%
200	89%
250	93%
300	96%
350	97%
400	98%

Three dimensions (2%), elbow-rest height, scrotale to posterior waist level/sitting, and interscye did not meet our criterion on the basis of samples of 400.

The sharp increase in the number of variables measurable on smaller samples has suggested that an N of 250 may be quite suitable when using matched samples of this type. The variables not satisfying our initial criterion when N=250 are, in addition to the three non-conforming measurements already mentioned, acromion-biceps length, bicristale breadth, waist depth, a full half dozen scrotale-to-waist level measures, scrotale, scrotale to anterior scye/sitting,

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* Based on the original criterion of 1% $\overline{X}$ or 0.1 inches.

and anterior and posterior neck lengths. Most of these measurements satisfy the criterion based on 1.5% rather than 1% of the mean value.

Analysis of WAF data shows similar results. All but 11 measurements appeared to be reliably measurable with matched samples of 250.

It will not always be possible to select the individual members of a survey sample on the basis of their heights and weights, either reported or measured. It is still possible to achieve much of the improvement of matched sampling by adjusting the sample statistics on the basis of the heights and weights of the sample itself. Table XIV shows the mean values for an assortment of 20 measured dimensions, age, reported height and weight, and a coded rank value, computed from the data for 10 samples constructed by selecting 350 subjects randomly from the 1967 survey sample. Table XV shows the similar results obtained by using samples of 250 and adjusting the results so that reported heights and weights agreed with those for the total survey means. We feel that the results are a clear indication of the potential of small sample surveys.

It can, perhaps, be argued that this analysis shows what might have been done in the past but does not directly address itself to the problems of future surveys which, presumably, will be designed to measure other dimensions. However, since this analysis has been based on such a large number of measurements of all types covering all parts of the body and

TABLE XIV

MEAN VALUES FROM RANDOM SAMPLES OF 350*

(No Adjustments)

Sample	Variable No. 1	2	3	4	5	6	7	8	9	10	11	12
1	80.3	84.8	108.9	172.2	60.2	167.7	93.1	177.1	98.0	87.4	98.3	171.9
2	80.4	85.3	109.2	173.5	60.5	167.8	93.2	177.6	98.3	86.9	98.5	172.8
3	80.4	85.3	109.4	175.2	60.7	168.3	93.3	177.6	99.0	88.4	99.1	174.9
4	80.5	85.7	109.8	173.6	60.6	167.9	93.3	178.1	98.6	87.3	98.4	173.4
5	80.2	85.1	109.3	174.7	60.5	168.0	93.2	177.4	99.2	88.0	98.9	173.8
6	80.4	85.2	109.4	174.6	60.5	168.7	93.5	177.8	99.0	87.7	99.0	174.2
7	79.9	84.9	108.9	172.8	60.3	167.7	93.0	176.9	98.4	87.6	98.6	172.5
8	80.2	85.2	109.1	172.3	60.4	168.2	93.4	177.5	98.1	87.1	98.3	172.1
9	80.0	84.9	109.0	173.7	60.5	168.0	93.1	177.2	98.7	87.6	98.8	173.1
10	80.3	84.6	108.7	173.5	60.1	168.3	93.2	177.0	98.8	87.7	98.6	172.8
Total 1967	80.3	85.1	109.2	173.6	60.4	168.1	93.2	177.3	98.6	87.6	98.6	173.1

Sample	Variable No. 13	14	15	16	17	18	19	20	21	22	23	24
1	48.0	32.7	35.2	69.4	57.5	19.9	15.6	29.8	12.0	27.0	19.1	11.5
2	48.4	32.9	35.2	69.8	57.5	19.9	15.6	29.7	12.1	27.1	19.2	11.5
3	48.4	33.0	35.4	69.7	57.6	19.9	15.6	29.7	12.0	27.1	19.2	11.5
4	48.3	32.8	35.2	69.8	57.5	19.8	15.6	30.1	12.0	27.1	19.2	11.6
5	48.5	33.0	35.4	69.6	57.7	19.9	15.6	29.9	12.0	27.1	19.1	11.5
6	48.4	32.9	35.3	69.8	57.5	19.9	15.6	30.2	12.0	27.0	19.2	11.6
7	48.2	32.8	35.2	69.4	57.4	19.8	15.6	29.4	11.9	27.0	19.0	11.5
8	48.0	32.6	35.2	69.7	57.4	19.9	15.5	30.5	12.0	27.0	19.1	11.6
9	48.3	32.7	35.3	69.5	57.5	19.8	15.6	29.7	12.0	27.0	19.1	11.6
10	48.4	32.9	35.2	69.5	57.6	20.0	15.6	30.7	12.0	26.9	19.1	11.7
Total 1967	48.2	32.8	35.3	69.6	57.5	19.9	15.6	30.0	12.0	27.0	19.1	--

VARIABLES

1 - Thumb-tip reach
2 - Crotch height
3 - Iliocristale height
4 - Weight
5 - Buttock-knee length
6 - Vertical trunk circumference
7 - Sitting height
8 - Height (stature)
9 - Chest circumference
10 - Waist circumference
11 - Buttock circumference
12 - Reported weight
13 - Bideltoid breadth
14 - Chest breadth
15 - Hip breadth
16 - Reported height
17 - Head circumference
18 - Head length
19 - Head breadth
20 - Age
21 - Menton-nasal root length
22 - Foot length
23 - Hand length
24 - Rank

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* All data in cm except weight and reported weight (lbs.), reported height (in.), age (yrs.), rank (coded). 1967 flying personnel survey data.

TABLE XV

MEAN VALUES FROM RANDOM SAMPLES OF 250*

Values Adjusted on the Basis of Reported Height and Weight

Sample	Variable No.											
	1	2	3	4	5	6	7	8	9	10	11	12
1	80.5	85.0	109.2	173.6	60.4	168.1	93.2	177.6	98.1	87.6	98.7	(172.3) †
2	80.1	85.2	109.1	173.6	60.4	167.9	93.1	177.3	98.8	87.2	98.5	(173.6)
3	80.3	84.9	108.9	173.6	60.4	168.0	93.2	177.3	98.1	87.3	96.6	(171.9)
4	80.2	85.1	109.2	173.2	60.5	167.6	93.2	177.3	98.6	87.8	98.6	(174.6)
5	80.6	85.5	109.6	173.4	60.5	167.8	93.0	177.6	98.7	87.6	98.5	(174.3)
6	80.2	85.2	109.3	173.7	60.6	167.7	93.0	177.4	98.7	87.7	98.6	(172.8)
7	80.2	85.0	109.2	173.8	60.4	167.6	93.3	177.3	99.0	87.5	98.6	(174.1)
8	80.2	84.9	109.0	173.6	60.3	168.4	93.3	177.3	99.1	87.5	98.8	(175.8)
9	80.2	85.2	109.2	173.0	60.5	167.9	93.2	177.3	98.2	87.6	98.8	(171.2)
10	80.2	85.2	109.1	173.4	60.4	168.0	93.2	177.3	98.4	87.6	98.5	(173.5)
Total 1967	80.3	85.1	109.2	173.6	60.4	168.1	93.2	177.3	98.6	87.6	98.6	173.1

Sample	Variable No.											
	13	14	15	16	17	18	19	20	21	22	23	24
1	[illegible]	[illegible]	35.4	(69.5) †	57.5	19.9	15.6	29.5	12.0	27.0	19.1	11.5
2	[illegible]	[illegible]	35.2	(69.6)	57.5	19.9	15.6	30.0	12.1	27.0	19.1	11.6
3	48.2	32.8	35.2	(69.6)	57.6	20.0	15.6	29.7	12.1	27.0	19.1	11.5
4	48.3	32.9	35.3	(69.7)	57.6	19.9	15.6	29.8	12.0	27.1	19.1	11.6
5	48.4	32.9	35.3	(69.8)	57.3	19.8	15.6	30.1	12.0	27.1	19.1	11.6
6	48.2	32.8	35.3	(69.7)	57.7	19.9	15.6	29.9	12.0	27.0	19.1	11.6
7	48.4	33.0	35.3	(69.6)	57.7	19.9	15.6	30.0	12.0	27.1	19.1	11.6
8	48.3	32.9	35.3	(69.9)	57.5	19.9	15.6	30.4	12.0	27.0	19.1	11.6
9	48.3	32.7	35.3	(69.5)	57.5	19.9	15.5	29.6	12.0	27.0	19.1	11.5
10	48.2	32.8	35.2	(69.4)	57.4	19.8	15.6	29.4	11.9	27.0	19.1	11.5
Total 1967	48.2	32.8	35.3	69.6	57.5	19.9	15.6	30.0	12.0	27.0	19.1	--

VARIABLES

1 - Thumb-tip reach
2 - Crotch height
3 - Iliocristale height
4 - Weight
5 - Buttock-knee length
6 - Vertical trunk circumference
7 - Sitting height
8 - Height (stature)
9 - Chest circumference
10 - Waist circumference
11 - Buttock circumference
12 - Reported weight
13 - Bideltoid breadth
14 - Chest breadth
15 - Hip breadth
16 - Reported height
17 - Head circumference
18 - Head length
19 - Head breadth
20 - Age
21 - Menton-nasal root length
22 - Foot length
23 - Hand length
24 - Rank

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* All data in cm except weight and reported weight (lbs.), reported height (in.), age (yrs.), rank (coded). 1967 flying personnel survey data.
† Not adjusted.

utilizing data for both men and women, it seems reasonable to suppose that these results will provide a realistic guide to the conduct of many future surveys.

CHAPTER IX

CONCLUSIONS AND RECOMMENDATIONS

We have, in the preceding pages, observed that the USAF's needs for anthropometric data are numerous and varied, that the resources for meeting these needs are substantial, that the available sampling and data acquisition strategies are of goodly number and take various forms. We have presented a definition of adequate accuracy and have demonstrated that such accuracy can be obtained from samples far smaller than those used in large-scale surveys. We have presented at least a prima facie case that the use of samples of a few hundred in surveys designed to obtain data on small groups of dimensions will, by making possible increased levels of preparation and care in the conduct of a survey and increased subject-time per measurement, provide more accuracy than is normally obtained in massive surveys.

Specific recommendations as to strategies for future data gathering are included at appropriate points in this report. To summarize, we make the following recommendations:

1. surveys should be task oriented;

2. data for the solution of design problems should be based on surveys limited to 40 measurements and to samples of 250-350 subjects, and whenever possible the sample should be one matched with or adjusted to appropriate population values for basic dimensions;

3. heights of student pilots and navigators aged 23 or 24 should be measured biennially to provide a running seven-year lead time on average USAF heights;

4. large numbers of USAF personnel, fliers and non-fliers, officers and non-officers, men and women, should be asked to report their heights and weights at least once every five years; such queries should be accompanied by additional questions designed to provide a basis for detecting major errors in the height-weight figures. These data should be used to adjust general USAF data to specific task-, command-, age-, rank-, and other subgroups within the USAF;

5. when research on the most satisfactory method of obtaining standardized anthropometric photographs has been completed, a five-year program, designed to provide a full set of these photographs should be undertaken;

6. the AMRL data bank should be expanded by the addition of new data whenever it becomes available;

7. all relevant data in the AMRL data bank should be analyzed to provide predictions of all dimensions for flying personnel and WAF's for 1980, 1985 and so on.

APPENDIX I

A LISTING OF VARIABLES IN THE AMRL DATA BANK

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A LISTING OF VARIABLES IN THE AMRL DATA BANK

A LISTING OF VARIABLES IN THE AMRL DATA BANK

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A LISTING OF VARIABLES IN THE AMRL DATA BANK

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APPENDIX II-A

REGRESSION EQUATIONS BASED ON MEASURED HEIGHT AND MEASURED WEIGHT*

	VARIABLE	MULTIPLE CORRELATION	(EQUATION)	STANDARD ERROR	"V"**
1	AGE	.151	(42.34 - .012HGT + .051WGT)	6.223	20.725
2	WEIGHT	1.000	(0.00 +0.000HGT +1.000WGT)	0.000	0.000
3	SKF SUBSCAP"R-LNGE	.656	(39.78 - .033HGT + .190WGT)	4.023	29.434
4	SKF TRICEPS-LANGE	.575	(21.71 - .021HGT + .158WGT)	4.201	32.966
5	SKF JUX"NIPPLE-LGE	.665	(41.57 - .040HGT + .243WGT)	5.010	36.816
6	SKF MAL XIPH"D-LGE	.702	(40.05 - .037HGT + .217WGT)	4.047	33.537
7	SKF SUPRAILIAC-LGE	.708	(67.89 - .068HGT + .450WGT)	8.277	31.692
8	SKF SUPRAPATELLA-L	.584	(14.94 - .011HGT + .073WGT)	1.873	25.550
9	SKF SUBSCAP"R-HARP†	.672	(408.82 - .329HGT +1.806WGT)	36.558	26.303
10	SKF TRICEPS-HARP"N†	.609	(253.90 - .214HGT +1.434WGT)	34.486	28.009
11	SKF SUPRAILIAC-HPN†	.692	(612.33 - .588HGT +3.879WGT)	74.653	30.828
12	GRIP STRENGTH	.399	(-.43 + .023HGT + .096WGT)	6.964	12.347
13	HEIGHT (STATURE)	1.000	(0.00 +1.000HGT +0.000WGT)	0.000	0.000
14	CERVICALE HEIGHT	.977	(-96.60 + .902HGT + .097WGT)	12.304	.809
15	ACROMION HEIGHT	.961	(-98.24 + .853HGT + .221WGT)	15.959	1.099
16	RADIALE HEIGHT	.924	(-45.58 + .634HGT + .254WGT)	17.411	1.550
17	STYLION HEIGHT	.843	(-53.72 + .499HGT + .199WGT)	21.212	2.450
18	DACTYLION HEIGHT	.775	(-78.25 + .405HGT + .185WGT)	22.191	3.303
19	SUPRASTERNALE HGHT	.976	(-58.05 + .833HGT + .187WGT)	11.905	.820
20	NIPPLE HEIGHT	.949	(-134.14 + .806HGT - .019WGT)	16.524	1.278
21	WAIST HT-OMPHALION	.925	(-207.06 + .733HGT - .159WGT)	17.905	1.681
22	ILIOCRISTALE HT	.914	(-150.79 + .690HGT + .107WGT)	19.499	1.786
23	BUTTOCK HEIGHT	.870	(-193.66 + .617HGT + .001WGT)	21.648	2.402
24	TROCHANTERION HGHT	.887	(-181.04 + .642HGT - .100WGT)	20.068	2.136
25	GLUTEAL FURROW HGT	.879	(-213.92 + .589HGT - .113WGT)	19.125	2.357
26	CROTCH HEIGHT	.861	(-199.35 + .613HGT - .216WGT)	21.052	2.474
27	PATELLA TOP HEIGHT	.855	(-99.19 + .352HGT + .010WGT)	13.249	2.518
28	KNEE CIRC HEIGHT	.859	(-113.87 + .342HGT + .019WGT)	12.741	2.566
29	FIBULAR HEIGHT	.845	(-109.53 + .310HGT - .012WGT)	12.034	2.743
30	CALF HEIGHT	.747	(-117.62 + .264HGT + .028WGT)	14.768	4.154
31	ANKLE HEIGHT	.472	(-21.66 + .092HGT - .026WGT)	10.130	7.384
32	SITTING HEIGHT	.789	(230.63 + .385HGT + .104WGT)	19.499	2.093
33	EYE HEIGHT/SITTING	.739	(179.71 + .349HGT + .061WGT)	20.309	2.509
34	MIDSHOULDER HT/SIT	.715	(137.25 + .261HGT + .260WGT)	19.162	2.966
35	ACROMION H"GHT/SIT	.666	(126.35 + .245HGT + .284WGT)	21.291	3.487
36	ELBOW REST HGT/SIT	.272	(151.02 + .029HGT + .280WGT)	25.088	9.970
37	KNEE HEIGHT/SITT"G	.887	(-54.15 + .332HGT + .133WGT)	11.480	2.058
38	POPLITEAL HGHT/SIT	.855	(-131.32 + .339HGT - .191WGT)	11.619	2.858
39	BUTTOCK-KNEE LNGTH	.812	(75.10 + .257HGT + .419WGT)	15.742	2.606
40	BUTTOCK-POPLITEAL	.729	(46.54 + .224HGT + .347WGT)	17.611	3.495
41	ACRM-BICEP CIR LVL	.485	(-13.32 + .111HGT + .041WGT)	13.204	6.948
42	SHOULDER-ELBOW LTH	.753	(-9.04 + .207HGT + .013WGT)	11.263	3.133
43	ACROMION-RADIALE L	.720	(-19.38 + .195HGT + .018WGT)	11.805	3.583
44	ELBOW-WRIST LENGTH	.738	(6.35 + .163HGT + .031WGT)	9.510	3.170
45	RADIALE-STYLION LH	.703	(-12.64 + .155HGT + .034WGT)	10.107	3.760
46	ELBOW-GRIP LENGTH	.753	(5.85 + .193HGT + .021WGT)	10.614	3.015
47	THUMB-TIP REACH	.680	(55.14 + .406HGT + .166WGT)	29.139	3.628
48	THUMB-TIP R"CH/XTD	.640	(91.87 + .438HGT + .155WGT)	34.693	3.872
49	SLEEVE INSEAM	.719	(-59.99 + .322HGT - .145WGT)	17.828	3.673
50	BIACROMIAL BREADTH	.482	(242.10 + .062HGT + .317WGT)	17.007	4.176

* BASED ON 1967 USAF SURVEY DATA. Values in mm, kg and years.
** Standard error/mean x 100.
† Tenths of mm.

REGRESSION EQUATIONS BASED ON MEASURED HEIGHT AND MEASURED WEIGHT*

	VARIABLE	MULTIPLE CORRELATION	(EQUATION)	STANDARD ERROR	"V"
51	BIDELTOID BREADTH	.806	(409.86 - .061HGT +1.042WGT)	15.172	3.145
52	CHEST BREADTH	.764	(287.91 - .059HGT + .829WGT)	13.692	4.176
53	WAIST BRDTH-OMPH"N	.870	(265.84 - .080HGT +1.065WGT)	11.760	3.799
54	BICRISTALE BREADTH	.649	(184.80 - .009HGT + .633WGT)	15.567	5.574
55	HIP BREADTH	.809	(230.82 - .001HGT + .714WGT)	11.061	3.137
56	HIP BREADTH SITT"G	.859	(271.33 - .035HGT + .970WGT)	11.791	3.120
57	ELBOW BRDTH BONE/R	.505	(33.38 + .016HGT + .052WGT)	3.119	4.404
58	ELBOW BRDTH BONE/L	.527	(32.64 + .017HGT + .051WGT)	2.979	4.200
59	F"ARM-F"ARM BR"DTH	.729	(530.88 - .134HGT +1.443WGT)	25.900	4.768
60	KNEE BR"DTH BONE/R	.644	(56.53 + .013HGT + .111WGT)	3.441	3.450
61	KNEE BR"DTH BONE/L	.652	(54.47 + .015HGT + .111WGT)	3.418	3.432
62	CHEST DEPTH	.792	(251.73 - .082HGT + .805WGT)	11.742	4.788
63	WAIST DEPTH-OMPH"N	.805	(264.98 - .116HGT + .940WGT)	12.915	5.791
64	BUTTOCK DEPTH	.851	(247.30 - .094HGT + .922WGT)	10.768	4.492
65	THIGH CLEARANCE HT	.821	(184.85 - .070HGT + .603WGT)	7.879	4.767
66	NECK CIRC -MAXIMUM	.719	(366.93 - .061HGT + .715WGT)	13.289	3.466
67	SHOULDER CIRCUM"CE	.841	(1000.43 - .142HGT +2.463WGT)	31.447	2.672
68	CHEST CIRC AT SCYE	.830	(936.07 - .205HGT +2.596WGT)	33.817	3.307
69	CHEST CIRCUMF"ENCE	.861	(957.13 - .264HGT +2.857WGT)	32.299	3.277
70	WAIST CIR-OMPHAL"N	.893	(899.02 - .352HGT +3.469WGT)	33.188	3.789
71	WAIST CIR-OMPH/SIT	.866	(966.50 - .390HGT +3.448WGT)	37.378	4.277
72	BUTTOCK CIRCUMF"CE	.932	(783.56 - .138HGT +2.574WGT)	20.007	2.029
73	BUTTOCK CIRCUM/SIT	.899	(863.81 - .179HGT +3.055WGT)	29.400	2.732
74	VERTICAL TRUNK CIR	.857	(710.83 + .325HGT +2.269WGT)	36.829	2.191
75	VERT TRUNK CIR/SIT	.814	(613.45 + .377HGT +1.910WGT)	40.341	2.501
76	SCROTALE-ANT WAIST	.504	(96.64 + .072HGT + .343WGT)	17.803	6.260
77	SCROTALE-A WAIST/S	.469	(49.13 + .105HGT + .111WGT)	15.004	5.899
78	SCRTL-SUPRASTERNLE	.697	(291.97 + .141HGT + .845WGT)	24.457	3.552
79	SCRTL-SUPRSTRNLE/S	.641	(191.69 + .209HGT + .419WGT)	22.954	3.611
80	SCRTL-ANT SCYE LVL	.623	(154.49 + .159HGT + .588WGT)	24.517	4.556
81	SCRTL-ANT SCYE L/S	.537	(59.26 + .225HGT + .157WGT)	24.914	5.140
82	SCRTL-A MIDSHOULDR	.752	(334.67 + .146HGT +1.039WGT)	24.500	3.167
83	SCRTL-A MDSHLDR/S	.687	(241.67 + .214HGT + .591WGT)	23.794	3.289
84	SCROTALE-PST WAIST	.617	(243.10 - .024HGT + .876WGT)	23.034	6.516
85	SCRTL-WAIST OVR BK	.592	(247.89 + .022HGT + .800WGT)	24.354	5.714
86	SCROTALE-P WAIST/S	.491	(242.95 - .001HGT + .716WGT)	27.116	7.420
87	SCRTL-WAIST/BUTT/S	.514	(258.77 + .010HGT + .684WGT)	25.031	6.334
88	SCROTALE-CERVICALE	.732	(351.02 + .166HGT +1.044WGT)	27.014	3.269
89	SCROTALE-CERVCLE/S	.711	(383.96 + .160HGT +1.021WGT)	27.923	3.307
90	SCRTL-PST SCYE LVL	.640	(268.39 + .118HGT + .854WGT)	27.399	4.407
91	SCRTL-PST SCYE L/S	.618	(311.33 + .106HGT + .845WGT)	28.249	4.375
92	SCRTL-P MIDSHOULDR	.766	(409.41 + .130HGT +1.226WGT)	26.159	3.065
93	SCRTL-MDSHLD OVR B	.740	(405.86 + .179HGT +1.102WGT)	27.986	3.060
94	SCRTL-P MDSHLDR/S	.738	(439.18 + .125HGT +1.227WGT)	28.329	3.245
95	SCRTL-MDSHLD O B/S	.740	(421.66 + .154HGT +1.137WGT)	27.644	3.097
96	UPPER THIGH CIRCUM	.897	(602.85 - .213HGT +2.096WGT)	19.616	3.335
97	UPPER THIGH C/SIT	.914	(566.47 - .193HGT +2.043WGT)	17.307	2.990
98	KNEE CIRCUMFERENCE	.848	(255.53 - .007HGT + .832WGT)	10.990	2.842
99	KNEE CIRCUM"CE/SIT	.855	(246.65 - .000HGT + .847WGT)	11.011	2.802
100	CALF CIRCUMF/RIGHT	.801	(350.66 - .081HGT + .946WGT)	13.623	3.663

* BASED ON 1967 USAF SURVEY DATA

REGRESSION EQUATIONS BASED ON MEASURED HEIGHT AND MEASURED WEIGHT*

	VARIABLE	MULTIPLE CORRELATION	(EQUATION)	STANDARD ERROR	"V"
101	CALF CIRCUMF/LEFT	.804	(336.11 - .072HGT + .925WGT)	13.272	3.594
102	ANKLE CIRCUMF"ENCE	.695	(168.00 - .010HGT + .424WGT)	9.093	4.058
103	SCYE CIRCUMFERENCE	.742	(338.94 - .015HGT + .982WGT)	18.629	3.852
104	BICEPS C-EXTEND/RT	.856	(363.85 - .137HGT +1.072WGT)	12.082	3.925
105	BICEPS C-EXTEND/LT	.867	(362.79 - .140HGT +1.088WGT)	11.668	3.839
106	BICEPS C-FLEXED/RT	.819	(354.71 - .112HGT + .984WGT)	12.960	3.958
107	BICEPS C-FLEXED/LT	.830	(346.61 - .111HGT + .990WGT)	12.533	3.902
108	ELBOW CIR-EXTENDED	.786	(218.30 - .021HGT + .556WGT)	8.861	3.203
109	ELBOW CIRC-FLEXED	.602	(188.63 + .026HGT + .448WGT)	13.936	4.461
110	LOWER ARM C-EXTEND	.802	(247.78 - .039HGT + .597WGT)	8.739	3.104
111	LOWER ARM C-FLEXED	.717	(240.41 - .023HGT + .560WGT)	11.010	3.699
112	WRIST CIRCUMF"ENCE	.589	(117.76 + .009HGT + .239WGT)	7.458	4.241
113	SLVE L/SPINE-SCYE	.527	(196.61 + .007HGT + .435WGT)	15.384	5.407
114	SLVE L/SPINE-ELBOW	.701	(173.97 + .206HGT + .383WGT)	18.662	3.081
115	SLVE L/SPINE-WRIST	.789	(203.17 + .356HGT + .424WGT)	21.601	2.378
116	ANTERIOR NECK LGTH	.483	(-106.16 + .142HGT - .355WGT)	14.731	17.464
117	POSTERIOR NECK LTH	.293	(1.15 + .091HGT - .177WGT)	16.074	12.139
118	SHOULDER LENGTH	.359	(56.24 + .054HGT + .086WGT)	11.765	7.086
119	DELTOID ARC	.434	(8.70 + .078HGT + .074WGT)	11.976	7.530
120	INTERSCYE	.414	(374.08 - .072HGT + .812WGT)	34.255	8.840
121	INTERSCYE MAXIMUM	.685	(360.58 + .059HGT + .868WGT)	21.970	3.570
122	WAIST FRONT-OMPH"N	.584	(214.11 + .058HGT + .499WGT)	17.969	4.446
123	CROTCH LGTH-OMPH"N	.725	(407.28 + .025HGT +1.461WGT)	30.544	4.326
124	WAIST BACK-OMPHL"N	.604	(90.29 + .198HGT + .165WGT)	18.929	4.034
125	FOOT LENGTH	.693	(51.69 + .114HGT + .092WGT)	8.569	3.170
126	INSTEP LENGTH	.622	(45.73 + .078HGT + .084WGT)	7.457	3.768
127	FOOT BREADTH	.507	(47.40 + .021HGT + .074WGT)	4.262	4.364
128	BALL-OF-FOOT CIRC	.584	(126.56 + .044HGT + .252WGT)	9.996	4.024
129	INSTEP CIRCUMF"NCE	.642	(136.89 + .039HGT + .291WGT)	9.276	3.610
130	HEEL CIRCUMFERENCE	.746	(126.03 + .091HGT + .304WGT)	9.403	2.770
131	BI-MALLEOLAR BRDTH	.547	(30.26 + .018HGT + .059WGT)	3.202	4.370
132	LAT"L MALLEOLUS HT	.463	(6.18 + .033HGT + .037WGT)	4.804	6.824
133	MED"L MALLEOLUS HT	.444	(21.93 + .032HGT + .039WGT)	5.088	5.939
134	HAND LENGTH	.654	(41.86 + .081HGT + .028WGT)	6.206	3.248
135	PALM LENGTH	.538	(27.94 + .043HGT + .019WGT)	4.562	4.213
136	HAND BR/METACARPLE	.494	(49.22 + .016HGT + .062WGT)	3.605	4.050
137	HAND BRTH AT THUMB	.517	(50.06 + .022HGT + .074WGT)	4.240	4.160
138	HAND C/METACARPALE	.539	(130.12 + .031HGT + .178WGT)	7.904	3.667
139	HAND C ROUND THUMB	.610	(161.52 + .029HGT + .257WGT)	8.564	3.326
140	HAND THICK/META-3	.271	(18.91 + .003HGT + .021WGT)	2.011	7.271
141	HEAD CIRCUMFERENCE	.423	(488.60 + .026HGT + .236WGT)	12.924	2.247
142	SAGITTAL ARC/INION	.167	(278.46 + .033HGT + .049WGT)	16.314	4.709
143	MINIMUM FRONTL ARC	.202	(131.58 - .005HGT + .081WGT)	7.707	5.668
144	BITRAGION-CORONAL	.327	(279.80 + .031HGT + .130WGT)	11.908	3.330
145	BITRAGN-MIN FRNTAL	.375	(252.92 + .017HGT + .144WGT)	9.218	2.993
146	BITRAG"N-SUBNASALE	.466	(256.10 - .001HGT + .223WGT)	9.019	3.077
147	BITRAGION-MENTON	.544	(259.28 + .008HGT + .300WGT)	10.348	3.170
148	BIT-SUBMANDIBULAR	.533	(242.94 - .001HGT + .393WGT)	13.319	4.299
149	BITRAG"N-POSTERIOR	.301	(252.41 + .004HGT + .204WGT)	14.252	4.840
150	HEAD LENGTH	.293	(158.61 + .017HGT + .057WGT)	6.449	3.245

* BASED ON 1967 USAF SURVEY DATA

REGRESSION EQUATIONS BASED ON MEASURED HEIGHT AND MEASURED WEIGHT*

VARIABLE	MULTIPLE CORRELATION	(EQUATION)	STANDARD ERROR	"V"
151 HEAD DIAGNL/MENTON	.445	(184.21 + .032HGT + .089WGT)	6.785	2.650
152 HD DIAG/INION-NOSE	.263	(172.90 + .017HGT + .092WGT)	9.807	4.471
153 EAR BREADTH	.194	(27.36 + .004HGT + .019WGT)	2.956	7.784
154 EAR LENGTH	.302	(45.29 + .007HGT + .047WGT)	4.061	6.156
155 EAR L ABVE TRAGION	.127	(19.96 + .005HGT + .006WGT)	2.914	9.920
156 HEAD BREADTH	.306	(147.06 - .003HGT + .082WGT)	5.156	3.305
157 MAXIMUM FRONTAL BR	.303	(98.42 + .004HGT + .057WGT)	4.342	3.742
158 BITRAGION BREADTH	.398	(128.32 - .002HGT + .107WGT)	5.093	3.574
159 BIZYGOMATIC BR"DTH	.456	(130.86 - .005HGT + .116WGT)	4.583	3.222
160 BIGONIAL BREADTH	.434	(119.36 - .017HGT + .159WGT)	6.231	5.312
161 EAR-TO-EAR BREADTH	.281	(151.26 + .013HGT + .082WGT)	7.752	4.117
162 BIOCULAR BREADTH	.191	(80.14 + .003HGT + .039WGT)	4.760	5.191
163 INTERPUPILLARY BRD	.191	(51.95 + .004HGT + .026WGT)	3.554	5.668
164 INTEROCULAR BR"DTH	.158	(28.43 + .001HGT + .019WGT)	2.746	8.243
165 NOSE BREADTH	.199	(35.96 - .003HGT + .031WGT)	2.875	8.115
166 LIP LENGTH	.173	(47.03 + .000HGT + .030WGT)	3.686	7.048
167 EAR PROTRUSION	.121	(15.14 + .002HGT + .015WGT)	3.339	15.420
168 SUBNASALE-NASAL RT	.197	(31.08 + .011HGT + .004WGT)	3.649	7.108
169 PHILTRUM LENGTH	.137	(15.72 - .002HGT + .020WGT)	2.737	17.638
170 LIP-TO-LIP LENGTH	.124	(7.91 + .008HGT - .023WGT)	3.798	21.916
171 MENTON-SUBNASALE L	.194	(46.87 + .010HGT + .026WGT)	5.168	7.489
172 MENTON-NASAL ROOT	.293	(77.06 + .021HGT + .034WGT)	5.822	4.839
173 GLABELLA-TO-VERTEX	.108	(61.71 + .020HGT - .022WGT)	9.651	10.404
174 NASAL ROOT-TO-VRTX	.173	(59.32 + .028HGT - .013WGT)	9.257	8.614
175 XTRNL CANTHUS-VRTX	.181	(80.17 + .022HGT + .004WGT)	7.575	6.339
176 PRONASALE-TO-VRTX	.192	(84.30 + .038HGT - .029WGT)	10.823	7.341
177 SUBNASALE-TO-VRTX	.229	(91.41 + .041HGT - .021WGT)	9.995	6.213
178 STOMION-TO-VERTEX	.241	(112.92 + .041HGT - .012WGT)	9.712	5.288
179 MENTON-TO-VERTEX	.284	(146.68 + .044HGT + .015WGT)	9.821	4.313
180 TRAGION-TO-VERTEX	.210	(103.76 + .015HGT + .025WGT)	5.963	4.435
181 GLABELLA-TO-WALL	.312	(160.05 + .019HGT + .059WGT)	6.405	3.147
182 NASAL ROOT-TO-WALL	.311	(159.02 + .019HGT + .056WGT)	6.246	3.097
183 XTRNL CANTHUS-WALL	.232	(152.44 + .009HGT + .054WGT)	6.416	3.607
184 PRONASALE-TO-WALL	.318	(184.09 + .016HGT + .080WGT)	7.110	3.135
185 SUBNASALE-TO-WALL	.290	(175.23 + .011HGT + .086WGT)	7.503	3.574
186 LIP PROMIN"CE-WALL	.294	(180.88 + .007HGT + .106WGT)	8.178	3.865
187 CHIN PROMINCE-WALL	.329	(174.44 + .002HGT + .159WGT)	9.884	4.828
188 TRAGION-TO-WALL	.135	(93.91 + .002HGT + .038WGT)	6.428	6.220

* BASED ON 1967 USAF SURVEY DATA

APPENDIX II-B

REGRESSION EQUATIONS BASED ON REPORTED HEIGHT AND REPORTED WEIGHT*

	VARIABLE	MULTIPLE CORRELATION	(EQUATION)	STANDARD ERROR	"V" **
1	AGE	.169	(50.64 - .018HGT + .062WGT)	6.205	20.664
2	WEIGHT	.975	(16.93 - .018HGT +1.092WGT)	4.787	2.758
3	SKF SUBSCAP"R-LNGE	.623	(42.84 - .036HGT + .206WGT)	4.169	30.503
4	SKF TRICEPS-LANGE	.548	(23.85 - .023HGT + .171WGT)	4.294	33.700
5	SKF JUX"NIPPLE-LGE	.633	(46.90 - .044HGT + .263WGT)	5.196	38.189
6	SKF MAL XIPH"D-LGE	.668	(44.33 - .041HGT + .235WGT)	4.225	35.020
7	SKF SUPRAILIAC-LGE	.676	(73.28 - .073HGT + .487WGT)	8.643	33.052
8	SKF SUPRAPATELLA-L	.558	(16.86 - .013HGT + .080WGT)	1.913	26.104
9	SKF SUBSCAP"R-HARP†	.641	(441.79 - .359HGT +1.961WGT)	37.898	27.267
10	SKF TRICEPS-HARP"N†	.574	(266.06 - .228HGT +1.531WGT)	35.606	28.918
11	SKF SUPRAILIAC-HPN†	.656	(662.99 - .639HGT +4.171WGT)	78.025	32.220
12	GRIP STRENGTH	.402	(2.43 + .019HGT + .114WGT)	6.954	12.328
13	HEIGHT (STATURE)	.956	(28.62 + .966HGT + .078WGT)	18.083	1.020
14	CERVICALE HEIGHT	.941	(-79.14 + .876HGT + .168WGT)	19.650	1.292
15	ACROMION HEIGHT	.928	(-79.91 + .825HGT + .303WGT)	21.484	1.479
16	RADIALE HEIGHT	.893	(-28.35 + .610HGT + .328WGT)	20.507	1.826
17	STYLION HEIGHT	.809	(-34.63 + .478HGT + .254WGT)	23.148	2.674
18	DACTYLION HEIGHT	.743	(-59.95 + .386HGT + .231WGT)	23.526	3.502
19	SUPRASTERNALE HGHT	.939	(-35.64 + .804HGT + .266WGT)	18.842	1.298
20	NIPPLE HEIGHT	.908	(-114.17 + .781HGT + .035WGT)	21.923	1.696
21	WAIST HT-OMPHALION	.896	(-214.64 + .728HGT - .148WGT)	20.901	1.963
22	ILIOCRISTALE HT	.890	(-153.83 + .680HGT + .151WGT)	21.832	2.000
23	BUTTOCK HEIGHT	.846	(-201.38 + .614HGT + .014WGT)	23.353	2.591
24	TROCHANTERION HGHT	.859	(-184.88 + .635HGT - .078WGT)	22.230	2.366
25	GLUTEAL FURROW HGT	.852	(-220.59 + .586HGT - .104WGT)	20.961	2.584
26	CROTCH HEIGHT	.838	(-214.02 + .619HGT - .216WGT)	22.584	2.654
27	PATELLA TOP HEIGHT	.831	(-100.28 + .347HGT + .030WGT)	14.211	2.701
28	KNEE CIRC HEIGHT	.837	(-116.77 + .338HGT + .037WGT)	13.607	2.741
29	FIBULAR HEIGHT	.820	(-110.38 + .306HGT + .005WGT)	12.882	2.936
30	CALF HEIGHT	.726	(-119.11 + .261HGT + .037WGT)	15.278	4.297
31	ANKLE HEIGHT	.459	(-23.62 + .092HGT - .027WGT)	10.208	7.441
32	SITTING HEIGHT	.749	(254.87 + .362HGT + .161WGT)	21.006	2.254
33	EYE HEIGHT/SITTING	.698	(204.68 + .326HGT + .116WGT)	21.580	2.666
34	MIDSHOULDER HT/SIT	.686	(161.87 + .238HGT + .329WGT)	19.930	3.085
35	ACROMION H"GHT/SIT	.640	(152.13 + .221HGT + .356WGT)	21.930	3.592
36	ELBOW REST HGT/SIT	.269	(179.68 + .007HGT + .345WGT)	25.108	9.978
37	KNEE HEIGHT/SITT"G	.867	(-54.28 + .326HGT + .163WGT)	12.398	2.223
38	POPLITEAL HGHT/SIT	.830	(-140.09 + .341HGT - .193WGT)	12.508	2.862
39	BUTTOCK-KNEE LNGTH	.800	(71.99 + .253HGT + .451WGT)	16.171	2.677
40	BUTTOCK-POPLITEAL	.716	(47.03 + .218HGT + .376WGT)	17.968	3.566
41	ACRM-BICEP CIR LVL	.470	(-12.14 + .108HGT + .049WGT)	13.323	7.010
42	SHOULDER-ELBOW LTH	.731	(-9.14 + .203HGT + .023WGT)	11.687	3.251
43	ACROMION-RADIALE L	.697	(-18.35 + .191HGT + .029WGT)	12.197	3.702
44	ELBOW-WRIST LENGTH	.726	(2.39 + .162HGT + .040WGT)	9.680	3.227
45	RADIALE-STYLION LH	.687	(-13.07 + .153HGT + .048WGT)	10.329	3.842
46	ELBOW-GRIP LENGTH	.738	(3.34 + .191HGT + .034WGT)	10.897	3.095
47	THUMB-TIP REACH	.660	(64.69 + .391HGT + .218WGT)	29.879	3.720
48	THUMB-TIP R"CH/XTD	.626	(87.96 + .433HGT + .181WGT)	35.212	3.930
49	SLEEVE INSEAM	.700	(-68.32 + .323HGT - .145WGT)	18.331	3.776
50	BIACROMIAL BREADTH	.481	(239.60 + .060HGT + .344WGT)	17.025	4.180

* BASED ON 1967 USAF SURVEY DATA. Values in mm, kg and years.
** Standard error/mean x 100.
† Tenths of mm.

REGRESSION EQUATIONS BASED ON REPORTED HEIGHT AND REPORTED WEIGHT*

	VARIABLE	MULTIPLE CORRELATION	(EQUATION)	STANDARD ERROR	"V"
51	BIDELTOID BREADTH	.783	(420.09 - .075HGT +1.133WGT)	15.944	3.305
52	CHEST BREADTH	.743	(299.61 - .072HGT + .907WGT)	14.183	4.326
53	WAIST BRDTH-OMPH"N	.842	(277.43 - .094HGT +1.156WGT)	12.859	4.154
54	BICRISTALE BREADTH	.639	(193.10 - .019HGT + .697WGT)	15.746	5.638
55	HIP BREADTH	.786	(237.31 - .010HGT + .770WGT)	11.637	3.300
56	HIP BREADTH SITT"G	.834	(282.11 - .048HGT +1.052WGT)	12.709	3.363
57	ELBOW BRDTH BONE/R	.497	(35.11 + .014HGT + .059WGT)	3.137	4.430
58	ELBOW BRDTH BONE/L	.518	(34.54 + .015HGT + .059WGT)	2.998	4.226
59	F"ARM-F"ARM BR"DTH	.714	(563.96 - .166HGT +1.598WGT)	26.501	4.879
60	KNEE BR"DTH BONE/R	.637	(58.62 + .011HGT + .124WGT)	3.467	3.475
61	KNEE BR"DTH BONE/L	.645	(56.51 + .012HGT + .124WGT)	3.443	3.457
62	CHEST DEPTH	.764	(267.66 - .097HGT + .878WGT)	12.412	5.081
63	WAIST DEPTH-OMPH"N	.775	(283.88 - .133HGT +1.024WGT)	13.773	6.176
64	BUTTOCK DEPTH	.820	(265.35 - .111HGT +1.003WGT)	11.742	4.899
65	THIGH CLEARANCE HT	.789	(193.61 - .079HGT + .655WGT)	8.466	5.122
66	NECK CIRC -MAXIMUM	.703	(379.41 - .074HGT + .787WGT)	13.612	3.550
67	SHOULDER CIRCUM"CE	.818	(1033.93 - .180HGT +2.688WGT)	33.418	2.839
68	CHEST CIRC AT SCYE	.804	(962.82 - .240HGT +2.820WGT)	36.047	3.525
69	CHEST CIRCUMF"ENCE	.832	(992.38 - .305HGT +3.108WGT)	35.166	3.568
70	WAIST CIR-OMPHAL"N	.865	(963.30 - .416HGT +3.794WGT)	37.020	4.226
71	WAIST CIR-OMPH/SIT	.836	(1035.03 - .454HGT +3.763WGT)	41.101	4.703
72	BUTTOCK CIRCUMF"CE	.902	(819.63 - .178HGT +2.794WGT)	23.794	2.413
73	BUTTOCK CIRCUM/SIT	.873	(926.70 - .240HGT +3.345WGT)	32.746	3.042
74	VERTICAL TRUNK CIR	.840	(780.47 + .257HGT +2.536WGT)	38.866	2.313
75	VERT TRUNK CIR/SIT	.799	(668.50 + .320HGT +2.141WGT)	41.800	2.591
76	SCROTALE-ANT WAIST	.485	(104.84 + .064HGT + .369WGT)	18.017	6.335
77	SCROTALE-A WAIST/S	.450	(54.56 + .099HGT + .124WGT)	15.167	5.963
78	SCRTL-SUPRASTERNLE	.675	(330.01 + .108HGT + .948WGT)	25.180	3.657
79	SCRTL-SUPRSTRNLE/S	.616	(219.40 + .185HGT + .490WGT)	23.545	3.704
80	SCRTL-ANT SCYE LVL	.605	(177.20 + .138HGT + .658WGT)	24.975	4.641
81	SCRTL-ANT SCYE L/S	.515	(73.21 + .211HGT + .196WGT)	25.311	5.221
82	SCRTL-A MIDSHOULDR	.733	(374.29 + .110HGT +1.164WGT)	25.304	3.271
83	SCRTL-A MDSHLDR/S	.670	(268.81 + .188HGT + .682WGT)	24.329	3.363
84	SCROTALE-PST WAIST	.601	(258.93 - .040HGT + .959WGT)	23.397	6.618
85	SCRTL-WAIST OVR BK	.580	(265.25 + .004HGT + .882WGT)	24.618	5.776
86	SCROTALE-P WAIST/S	.476	(261.32 - .018HGT + .783WGT)	27.375	7.490
87	SCRTL-WAIST/BUTT/S	.497	(272.72 - .004HGT + .744WGT)	25.308	6.404
88	SCROTALE-CERVICALE	.719	(387.18 + .130HGT +1.183WGT)	27.528	3.331
89	SCROTALE-CERVCLE/S	.694	(422.80 + .124HGT +1.147WGT)	28.610	3.388
90	SCRTL-PST SCYE LVL	.627	(295.38 + .089HGT + .957WGT)	27.770	4.467
91	SCRTL-PST SCYE L/S	.600	(342.76 + .078HGT + .940WGT)	28.743	4.452
92	SCRTL-P MIDSHOULDR	.754	(440.87 + .098HGT +1.369WGT)	26.728	3.132
93	SCRTL-MDSHLD OVR B	.731	(438.61 + .144HGT +1.250WGT)	28.375	3.103
94	SCRTL-P MDSHLDR/S	.720	(471.68 + .093HGT +1.356WGT)	29.097	3.333
95	SCRTL-MDSHLD O B/S	.724	(446.83 + .127HGT +1.255WGT)	28.320	3.173
96	UPPER THIGH CIRCUM	.856	(616.90 - .234HGT +2.248WGT)	22.884	3.891
97	UPPER THIGH C/SIT	.878	(590.68 - .220HGT +2.208WGT)	20.401	3.525
98	KNEE CIRCUMFERENCE	.829	(268.63 - .022HGT + .912WGT)	11.597	2.999
99	KNEE CIRCUM"CE/SIT	.833	(261.12 - .016HGT + .926WGT)	11.724	2.983
100	CALF CIRCUMF/RIGHT	.776	(365.78 - .096HGT +1.032WGT)	14.348	3.858

* BASED ON 1967 USAF SURVEY DATA

REGRESSION EQUATIONS BASED ON REPORTED HEIGHT AND REPORTED WEIGHT*

	VARIABLE	MULTIPLE CORRELATION	(EQUATION)	STANDARD ERROR	"V"
101	CALF CIRCUMF/LEFT	.781	(350.36 - .087HGT +1.011WGT)	13.931	3.772
102	ANKLE CIRCUMF"ENCE	.685	(176.48 - .019HGT + .471WGT)	9.208	4.109
103	SCYE CIRCUMFERENCE	.725	(355.30 - .033HGT +1.078WGT)	19.119	3.953
104	BICEPS C-EXTEND/RT	.826	(379.15 - .153HGT +1.171WGT)	13.147	4.271
105	BICEPS C-EXTEND/LT	.836	(380.52 - .158HGT +1.189WGT)	12.815	4.217
106	BICEPS C-FLEXED/RT	.794	(367.41 - .126HGT +1.076WGT)	13.732	4.194
107	BICEPS C-FLEXED/LT	.804	(363.98 - .129HGT +1.084WGT)	13.351	4.187
108	ELBOW CIR-EXTENDED	.776	(229.92 - .034HGT + .618WGT)	9.046	3.270
109	ELBOW CIRC-FLEXED	.597	(192.54 + .019HGT + .494WGT)	14.008	4.484
110	LOWER ARM C-EXTEND	.788	(258.60 - .051HGT + .661WGT)	8.995	3.195
111	LOWER ARM C-FLEXED	.707	(250.19 - .034HGT + .621WGT)	11.173	3.753
112	WRIST CIRCUMF"ENCE	.580	(122.94 + .004HGT + .265WGT)	7.519	4.276
113	SLVE L/SPINE-SCYE	.519	(210.39 - .006HGT + .487WGT)	15.481	5.441
114	SLVE L/SPINE-ELBOW	.685	(189.22 + .189HGT + .446WGT)	19.060	3.146
115	SLVE L/SPINE-WRIST	.775	(213.69 + .339HGT + .499WGT)	22.247	2.450
116	ANTERIOR NECK LGTH	.456	(-113.24 + .147HGT - .384WGT)	14.970	17.748
117	POSTERIOR NECK LTH	.256	(7.82 + .087HGT - .177WGT)	16.250	12.272
118	SHOULDER LENGTH	.358	(56.05 + .052HGT + .098WGT)	11.770	7.089
119	DELTOID ARC	.416	(13.03 + .073HGT + .084WGT)	12.085	7.598
120	INTERSCYE	.390	(365.87 - .070HGT + .847WGT)	34.649	8.942
121	INTERSCYE MAXIMUM	.682	(377.17 + .039HGT + .974WGT)	22.061	3.585
122	WAIST FRONT-OMPH"N	.565	(246.48 + .032HGT + .574WGT)	18.257	4.517
123	CROTCH LGTH-OMPH"N	.704	(437.98 - .005HGT +1.593WGT)	31.505	4.462
124	WAIST BACK-OMPHL"N	.578	(110.03 + .179HGT + .219WGT)	19.381	4.131
125	FOOT LENGTH	.683	(53.02 + .110HGT + .113WGT)	8.685	3.213
126	INSTEP LENGTH	.615	(47.04 + .074HGT + .102WGT)	7.509	3.794
127	FOOT BREADTH	.503	(49.28 + .019HGT + .084WGT)	4.274	4.376
128	BALL-OF-FOOT CIRC	.577	(134.37 + .036HGT + .286WGT)	10.060	4.050
129	INSTEP CIRCUMF"NCE	.630	(144.68 + .031HGT + .324WGT)	9.397	3.657
130	HEEL CIRCUMFERENCE	.737	(134.57 + .081HGT + .348WGT)	9.548	2.813
131	BI-MALLEOLAR BRDTH	.542	(31.14 + .017HGT + .066WGT)	3.217	4.390
132	LAT"L MALLEOLUS HT	.454	(6.43 + .032HGT + .041WGT)	4.830	6.861
133	MED"L MALLEOLUS HT	.435	(23.62 + .030HGT + .048WGT)	5.113	5.968
134	HAND LENGTH	.640	(42.38 + .079HGT + .040WGT)	6.299	3.297
135	PALM LENGTH	.533	(27.62 + .042HGT + .026WGT)	4.582	4.231
136	HAND BR/METACARPLE	.493	(53.33 + .012HGT + .077WGT)	3.607	4.053
137	HAND BRTH AT THUMB	.515	(52.62 + .019HGT + .087WGT)	4.248	4.167
138	HAND C/METACARPALE	.536	(136.56 + .024HGT + .206WGT)	7.922	3.676
139	HAND C ROUND THUMB	.607	(168.54 + .021HGT + .292WGT)	8.593	3.337
140	HAND THICK/META-3	.271	(20.72 + .001HGT + .026WGT)	2.011	7.272
141	HEAD CIRCUMFERENCE	.415	(498.63 + .017HGT + .269WGT)	12.974	2.256
142	SAGITTAL ARC/INION	.156	(286.72 + .027HGT + .065WGT)	16.345	4.718
143	MINIMUM FRONTL ARC	.194	(131.98 - .006HGT + .087WGT)	7.720	5.677
144	BITRAGION-CORONAL	.317	(287.21 + .025HGT + .150WGT)	11.950	3.342
145	BITRAGN-MIN FRNTAL	.371	(260.59 + .010HGT + .168WGT)	9.234	2.998
146	BITRAG"N-SUBNASALE	.462	(264.25 - .008HGT + .253WGT)	9.044	3.086
147	BITRAGION-MENTON	.533	(268.99 - .000HGT + .335WGT)	10.441	3.198
148	BIT-SUBMANDIBULAR	.518	(253.98 - .011HGT + .433WGT)	13.462	4.346
149	BITRAG"N-POSTERIOR	.299	(253.80 + .001HGT + .225WGT)	14.264	4.844
150	HEAD LENGTH	.287	(182.61 + .013HGT + .069WGT)	6.460	3.251

* BASED ON 1967 USAF SURVEY DATA

REGRESSION EQUATIONS BASED ON REPORTED HEIGHT AND REPORTED WEIGHT*

	VARIABLE	MULTIPLE CORRELATION	(EQUATION)	STANDARD ERROR	"V"
151	HEAD DIAGNL/MENTON	.426	(191.75 + .026HGT + .106WGT)	6.853	2.677
152	HD DIAG/INION-NOSE	.260	(179.25 + .012HGT + .111WGT)	9.815	4.474
153	EAR BREADTH	.192	(27.12 + .004HGT + .020WGT)	2.957	7.787
154	EAR LENGTH	.284	(48.58 + .005HGT + .052WGT)	4.084	6.191
155	EAR L ABVE TRAGION	.124	(19.78 + .005HGT + .006WGT)	2.915	9.923
156	HEAD BREADTH	.296	(149.44 - .005HGT + .089WGT)	5.174	3.317
157	MAXIMUM FRONTAL BR	.298	(99.79 + .003HGT + .064WGT)	4.349	3.749
158	BITRAGION BREADTH	.390	(130.27 - .005HGT + .117WGT)	5.113	3.588
159	BIZYGOMATIC BR"DTH	.453	(134.97 - .009HGT + .132WGT)	4.592	3.228
160	BIGONIAL BREADTH	.433	(126.06 - .022HGT + .181WGT)	6.234	5.314
161	EAR-TO-EAR BREADTH	.274	(153.64 + .011HGT + .091WGT)	7.769	4.126
162	BIOCULAR BREADTH	.188	(81.40 + .002HGT + .043WGT)	4.763	5.194
163	INTERPUPILLARY BRD	.192	(53.15 + .002HGT + .031WGT)	3.563	5.666
164	INTEROCULAR BR"DTH	.163	(28.16 + .001HGT + .022WGT)	2.743	8.235
165	NOSE BREADTH	.197	(37.20 - .004HGT + .035WGT)	2.876	8.119
166	LIP LENGTH	.175	(49.22 - .002HGT + .036WGT)	3.685	7.046
167	EAR PROTRUSION	.113	(15.76 + .002HGT + .016WGT)	3.342	15.434
168	SUBNASALE-NASAL RT	.184	(32.43 + .010HGT + .007WGT)	3.659	7.126
169	PHILTRUM LENGTH	.128	(17.10 - .003HGT + .022WGT)	2.740	17.659
170	LIP-TO-LIP LENGTH	.120	(7.26 + .008HGT - .026WGT)	3.800	21.927
171	MENTON-SUBNASALE L	.182	(49.61 + .008HGT + .031WGT)	5.180	7.507
172	MENTON-NASAL ROOT	.276	(81.43 + .018HGT + .042WGT)	5.852	4.864
173	GLABELLA-TO-VERTEX	.097	(63.06 + .019HGT - .021WGT)	9.662	10.416
174	NASAL ROOT-TO-VRTX	.162	(60.70 + .027HGT - .010WGT)	9.275	8.631
175	XTRNL CANTHUS-VRTX	.168	(82.88 + .020HGT + .009WGT)	7.593	6.354
176	PRONASALE-TO-VRTX	.173	(88.07 + .035HGT - .023WGT)	10.863	7.369
177	SUBNASALE-TO-VRTX	.207	(95.73 + .038HGT - .012WGT)	10.043	6.243
178	STOMION-TO-VERTEX	.217	(118.38 + .037HGT - .003WGT)	9.768	5.319
179	MENTON-TO-VERTEX	.262	(153.32 + .039HGT + .027WGT)	9.885	4.341
180	TRAGION-TO-VERTEX	.201	(105.77 + .013HGT + .030WGT)	5.975	4.444
181	GLABELLA-TO-WALL	.308	(163.40 + .015HGT + .071WGT)	6.415	3.152
182	NASAL ROOT-TO-WALL	.304	(163.01 + .015HGT + .068WGT)	6.261	3.104
183	XTRNL CANTHUS-WALL	.226	(156.84 + .005HGT + .065WGT)	6.424	3.612
184	PRONASALE-TO-WALL	.313	(189.18 + .012HGT + .095WGT)	7.124	3.141
185	SUBNASALE-TO-WALL	.285	(180.02 + .007HGT + .100WGT)	7.513	3.579
186	LIP PROMIN"CE-WALL	.289	(185.62 + .003HGT + .120WGT)	8.192	3.871
187	CHIN PROMINCE-WALL	.321	(178.72 - .002HGT + .175WGT)	9.913	4.842
188	TRAGION-TO-WALL	.131	(94.92 + .001HGT + .042WGT)	6.431	6.223

* BASED ON 1967 USAF SURVEY DATA

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